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WINTER WHEAT AND SORGHUM PRODUCTION IN THE SOUTHERN GREAT PLAINS UNDER LIMITED RAINFALL

By

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and

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Division of Dry Land Agriculture
Bureau of Plant Industry

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INTRODUCTION

The crop failures and the spectacular dust storms that have ravaged the Great Plains during the last few years have focused public attention on the region and have aroused much speculation regarding its future for farming. This attention has been directed most closely to that portion consisting of southwestern Kansas, western Oklahoma, southeastern Colorado, and part of the Texas Panhandle. It is here that some of the worst soil blowing has taken place. Hasty judgment has led to condemnation of the whole area for crop production by some people, and its no less vigorous support by others. No intensive effort has been made to get at the facts and to determine from past experience what is likely to happen in the future.

To understand better the present status of agriculture in this area it is necessary to have some knowledge of the changes that have taken place since its settlement.

The area consists largely of fertile plains, with vast expanses of nearly level land where large units of machinery can be handled without difficulty. Prior to the perfection of tractors and tractor-drawn machinery, agriculture within it was approaching stability with the production of grain and feed crops incidental to the production of livestock. Wheat occupied a place as a cash crop, but was not all-important.

Early in its settlement, particularly in the early nineties, wheat production had increased by leaps and bounds for a few years. But the disastrous droughts of 1893 and succeeding years forced most of the early settlers to leave the country, and gave wheat growing a set-back from which it did not recover for years. The increase in wheat prices brought about by the World War is largely responsible for the post-war acreage expansion.

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Without power machinery the expansion would no doubt have been slow, but the improvement of the tractor and the development of large-type power machinery such as the one-way plow and the combine harvester changed the situation. The use of power machinery made it possible for one man to handle a large acreage of land. The return from a good crop of wheat was higher than could be obtained through general farming, and the wheat acreage was greatly increased. Some land previously devoted to other crops was planted to wheat, and immense areas that had been previously regarded as too risky for growing wheat were brought into production. The way was opened to big-scale farming, which offered a fertile field for the large operator and the resident and nonresident speculator.

The area underwent its greatest development during a series of years with good prices and above-average yields, when many extensive wheat growers reaped small fortunes. This intensified the belief that extensive wheat growing was the way to prosper. The gambling instinct, inherent in all of us, made the wheat farmer willing to take the risk of complete failure in order to have a chance to make a real "killing" if conditions were favorable. Most of these wheat farmers have taken losses that have fallen to their lot within recent years without complaint and with a steadfast faith in the future. Most of them retain the belief that with the return of normal rainfall the area will resume its place in wheat production.

There is much basis for the belief that hard wheat of good quality can be economically grown in this area, and there is also the certainty that years of failure and successive years of failure with wheat will recur. Very few farmers have enough capital to endure successive years of failure, maintain decent living standards, and be in position to go forward when good conditions return. The question arises as to whether there is not some other crop, or some combination of crops and cultural practices that could be used in connection with wheat that would distribute income more evenly between years. Fortunately there is a means of answering this question.

Within, or bordering on the area in question, are stations where the Division of Dry Land Agriculture of the United States Department of Agriculture, either independently or in cooperation with the States, has conducted experiments in crop production during the past 25 years. Most adapted crops have been grown under a wide variety of cultural methods. Climatic records have been kept, so that the crop yields show production under measured conditions of precipitation and temperature. Soil-moisture determinations have been made, so that the effectiveness of rainfall in supplying moisture to the soil can be measured. By utilizing the knowledge obtained on crop growth under specified climatic conditions, it is possible to extend the application of station results to the entire period for which climatic records are available and to localities outside those in which the stations are located but which have similar conditions of soil and climate.

PURPOSE AND METHOD OF STUDY

The purpose of the study reported herein was to determine and make available for the principal crops of the area the yields that might be obtained during a long-time period under the rainfall conditions prevailing in the different localities. No attempt was made to

establish a definite farming system for the whole area. The agricultural history of the area is relatively short. Many of the farmers moved in following the post-war boom, and with many of the others experience with certain crops is limited to a relatively small number of years. It is believed that knowledge of what may be expected from the major crops during a long series of years will enable a farmer to apply these results to his own conditions. He can then decide whether to stick to wheat growing with its failures in poor years, and higher income in good years, or to adopt a more diversified system with income more evenly distributed between good and bad years, but with much lower returns in good years. The decision, when reached, should be based on the best available information obtained through long-time records, not entirely on information obtained individually during a relatively short term of years. In most cases individual experiences are too short to serve as a basis for making such a decision.

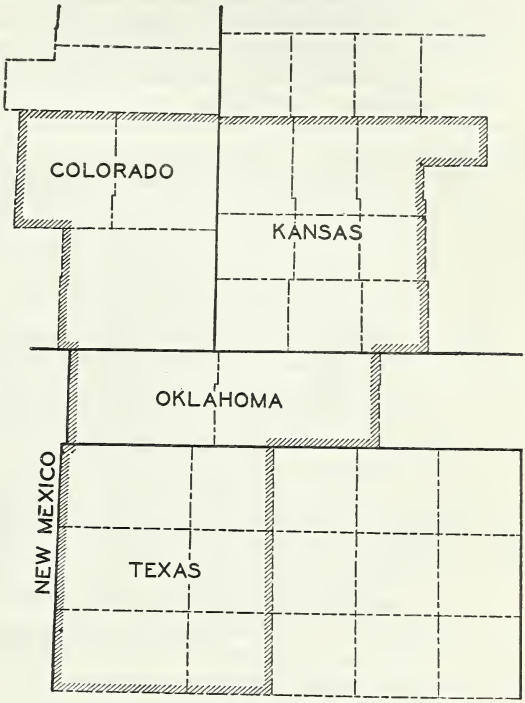

FIGURE 1.—Map of area studied.

The method of study employed was to establish the relationship between rainfall, soil moisture, and crop yields for experiment stations within or near the area. Formulas representing this relationship were tested at other stations having climate and crop-yield data. They were then applied to the whole area under study for the purpose of estimating crop yields in sections where records of precipitation only were available.

THE AREA STUDIED

The area included in this study consists of nine counties in southwestern Kansas, two in the Oklahoma Panhandle, six in the Texas Panhandle, and three in southeastern Colorado (fig. 1). Some climatic data from outside this area are used for the purpose of better establishing boundaries.

This particular area was chosen for study because some of the greatest recent agricultural expansion had taken place within its borders; the most important crops are winter wheat and sorghums, and the area is a cross section of that subjected most often to injury through soil blowing.

The rapid expansion explains the short agricultural history of part of the area; in the nine counties in Kansas, wheat plantings increased from 196,528 acres in 1920 to 1,086,659 acres in 1930. Five counties were planting less than 10,000 acres of wheat each in 1920, while in 1930 only three of them seeded less than 100,000 acres.

SOILS

This area is largely a nearly level to gently undulating plain dotted by small shallow depressions and cut by the rather broad, shallow valleys of the Arkansas, Cimarron, and Canadian Rivers and their tributaries. The valleys are flanked in many places by areas of rough land and sand hills, some of which are several miles wide.

The soils have developed under the influence of a subhumid or semiarid, continental climate, which is characterized by low normal precipitation and a wide seasonal range of temperatures.

Climate of this type gives rise to a short-grass native vegetation, under which soils of thick, brown to nearly black surface layers develop on fine-textured materials. Precipitation is not sufficient to leach the soluble salts to depths of more than about 3 feet, and most of the soils have developed a friable subsoil containing a layer of lime carbonate enrichment at depths from 1 to 3 feet.

For the production of crops it may be said that, in general, the soils contain an abundance of plant nutrients, are deep enough to hold for crop use all moisture that penetrates their surface layer, and that the greatest limiting factor of crop yields, when the best tillage practices and seed are used, is precipitation.

Owing to rather wide ranges in annual precipitation, soil parent materials, and topographic features, many soil series and types are represented. Detailed reconnaissance erosion surveys for most of the counties in the area have now been made and reported (*9*) [1] by the Soil Conservation Service.

On the basis of topography and texture the soils may be grouped into tillable and nontillable soils. Many portions of the tillable soils are in native sod, and some, usually small portions, of the nontillable soils are tilled or have been.

TILLABLE SOILS

The tillable soils are on nearly level to undulating topography and range from clay loams to loamy sands. This group may be further divided on the basis of texture, which largely determines the efficiency of the soil in absorbing and holding moisture for plant use. These subgroups are the fine-texture group and the sandy group.

FINE-TEXTURE GROUP

The fine-textured group consists chiefly of the clay loams, silty clay loams, silt loams, and very fine sandy loams of the Richfield, Pullman, Colby, Abilene, Tillman, and Roscoe series. These soils are developed on the nearly level plains that constitute most of the area. They are the so-called "hard lands," which were originally covered with nearly pure stands of native short grasses (buffalo grass and blue grama grass), and which are now largely devoted to the growing of wheat.

[1] Italic numbers in parentheses refer to Literature Cited p. 59.

The topography is admirably suited to the use of big machinery, and the soils are capable of storing large amounts of moisture for crop use, which gives rise to extremely high yields on these fertile soils in years of high precipitation.

Soils in this group, especially the clay loam and silty clay loam types, hold so much water in the surface few inches, where it can evaporate readily, that heavy rains are required during the summer for water to penetrate into the subsoil, where it will be protected from evaporation.

Throughout the area, crop failures are more common on the heavy soils than on the soils containing considerable sand in the surface layer. This is the result of greater moisture losses, due to evaporation and perhaps to surface run-off from the fine-texture soils.

SANDY GROUP

Except for the very fine sandy loam, the sandy group consists of the sandy loams, loamy sands, and occasional areas of very fine sand. The principal series represented in this group are the Pratt, Miles, Vernon, Abilene, Amarillo, and Enterprise.

In general, these soils are deep and have water-holding capacities sufficiently high to hold within depths readily available to plant roots all the moisture they receive. They originally supported a tall or mixed grass vegetation, indicating a deeper penetration of water than on the fine-texture soils. They do not produce as high crop yields in very favorable years as the fine-texture soils, but they produce better in fair or poor years, and failures on them are less frequent.

The soils in the sandy group erode rather easily under influence of wind action, which makes it difficult to establish and maintain stands of wheat on them. For this reason a much greater proportionate area of these soils is devoted to growing sorghums than on the hard land. This soil group is well suited to growing the grain sorghums, and yields are generally good with failures relatively infrequent.

NONTILLABLE SOILS

The nontillable soils are those occurring on slopes where surface run-off is conducive to rapid soil erosion, and sands that are very unstable under cultivation. Unfortunately many small fields or parts of fields are under cultivation on slopes which erode rather rapidly, and on sands that shift so readily in each wind that even crops like sorghums or corn often fail to get started. However, the cultivated portions of generally nontillable areas represent a small percentage of the total, and nearly all farmers in the section now realize the folly of farming these locations when nearly level, more stable soils are plentiful.

WIND EROSION

Wind erosion is an ever-present problem, particularly on the more sandy soils. During the past few years it has reached tremendous proportions and has spread to all types of soil and damaged pastures as well as cultivated fields. The cause has been a series of drought years, during which crops failed and little or no vegetative cover was left on the ground, combined with a series of dry open winters that mellowed the soil so that it blew easily at a time when wheat had

failed to come up or had made too little growth to form a cover. The seriousness of the situation was accentuated by feed shortage that made the complete utilization of the short crops that were grown a practical necessity, and by financial difficulties that prevented a majority of farmers from performing the preventive cultivation, which they knew was necessary, at the time when it would have been most effective.

The specific causes of wind erosion, and the cropping and cultural practices used in combating it are subjects requiring too much space to be discussed in detail here. They have been covered by Chilcott (*2*), Call (*1*), Cole and Morgan (*4*), Kellogg (*10*), and others in publications on that particular subject.

The control of wind erosion on the areas where it is now prevalent must be accomplished, or future agriculture is out of the question. This control depends upon the return of normal or above-normal rainfall and upon the cultural and cropping practices used. For the present, the question of bringing the land under some measure of control until natural controlling factors come into play is the all-important one. While this is being accomplished, the question of how frequently conditions conducive to soil movement will recur should be considered.

On most of the soils adapted to wheat in the area, wind erosion is much more frequently the result of factors that contribute to crop failure than it is a cause of failure. With any particular soil, the frequency with which a condition conducive to blowing is reached depends on the frequency with which crops, or more especially winter wheat, may be expected to fail. Crop failure and wind erosion are closely associated, and the number of times that crops may be expected to fail is at least a good indication of the number of times that conditions favorable to blowing may be expected.

The present series of years has taught farmers the seriousness of the problem. It has further shown them how to combat erosion by cultivation, and has shown them the necessity of leaving a crop residue on fields that would otherwise be bare over winter. When land has again been brought under control, more intelligent and concerted effort will be made to check wind erosion before it reaches destructive proportions than has been the case heretofore.

Land that is too susceptible to wind erosion must eventually be retired from cultivation. At the present time it is a menace to surrounding land.

CLIMATIC CONDITIONS

The precipitation for the area ranges from above 19 inches along the eastern and southern borders to as low as 14 inches along the western border. Most of the precipitation is during the summer months, and the winters are, as a rule, dry and open. Precipitation is erratic from year to year and droughts are relatively frequent.

The soil is not frozen nor is it covered with snow for long periods during the winter. The mellowing of the surface soil by light snows or showers during the winter often loosens it to such an extent that it is subject to blowing unless well protected by vegetative cover.

The relative humidity decreases from an average of about 60 percent in the eastern part of the area to less than 55 percent in the western part.

Evaporation for the 6 summer months from an open tank 2 feet in depth set 21 inches into the ground and the water kept at approxi-

mately the ground level ranges from 48 to 55 inches at three stations within the area. Colby, somewhat to the north of the area under study, showed a much lower evaporation than Amarillo, Dalhart, or Garden City. Evaporation in southeastern Colorado, located at a higher altitude, is probably as low as at Colby.

Summer temperatures run high over the entire area. Average July maximum temperatures are generally above 90° F., and days with maximum temperatures above 100° are frequent. This is probably one reason why winter wheat that matures before the hottest part of the summer and sorghums that are able to endure hot, dry weather are adapted crops. Average summer temperatures decrease rapidly west of the area under study.

Winter wheat frequently remains green over winter in the southern part of the area but generally kills back and has a dormant period in the northern part.

Wind velocities are relatively high, particularly during the late winter and early spring. The occurrence of relatively high wind velocities in February and March, when the soil has been mellowed by winter conditions and when wheat has not started spring growth, makes these months the critical period for wheat.

CROPS COMMONLY GROWN

Winter wheat and sorghum predominate in the area with corn of somewhat lesser importance and spring-sown small grains occupying an unimportant place. Winter wheat predominates on the hard lands, but sorghum reaches its maximum acreage on soils too sandy for wheat. Sorghums, however, can be grown on the hard lands.

The sorghums grown include all the most important types, milo being important for grain production and kafir for both a grain and a feed crop. Hegari is used as bundle feed, particularly in the southern part. Broomcorn is important in some parts. Feterita, Sudan grass, and forage sorghums are grown in all sections.

In their response to rainfall, the different sorghums react much the same. For this reason only two of the more important ones, milo and kafir, are considered in this study. It is believed that a measure of the grain and forage production of these crops will give a fair idea of the grain and forage yields of sorghums. Sudan grass is usually used for pasture. Broomcorn is a specialized crop with rather narrow acreage limits, which could not be widely extended without glutting the market. Milo and kafir fit in well with livestock production, and acreage increases of these crops could be utilized on the farms.

Winter wheat is the major crop over most of the area, but other crops are grown more extensively in localities where wheat does not do well. The growth of sorghums on hard land has been limited in part because wheat production has been more profitable, and in part because the extensive type of farming adapted to wheat has not fitted in with the production of row crops. Then too, sorghums do better on light than on heavy soils. The recent development of grain sorghums that can be handled with a combine harvester may cause a change in the acreage devoted to them.

Studies of winter wheat, milo, and kafir form a good basis for determining the crop-producing possibilities of the area. Winter wheat will be considered first.

STUDIES WITH WINTER WHEAT

Results with winter wheat at Garden City and Colby, Kans., form the basis for most of the deductions reached. Colby is somewhat north of the area under study, but it is believed that conditions at Colby more nearly resemble those in the portion of the area having a high altitude than conditions at Garden City.

CLIMATIC FACTORS INFLUENCING WINTER WHEAT

The climatic factors that most affect winter wheat are precipitation, evaporation, relative humidity, and temperature. All these factors are important but are interdependent to a considerable degree. High temperatures are usually associated with low rainfall, and high rainfall in spring and early summer is usually accompanied by low temperatures. High evaporation is an effect of low humidity, and low humidity is usually a result of low rainfall. For these reasons, study of crop production in connection with a single climatic factor shows a higher relationship than a single factor might be expected to contribute. Precipitation records have been kept at more places than other climatic records. They have formed the basis for the present studies. This has been done as a convenience and does not discount the importance of other climatic factors. Cole [2] found nearly as strong a negative correlation for evaporation as the correlation for precipitation was positive. Daniel (*5*) obtained a high negative correlation between evaporation and yield. However, evaporation records have been kept at only a few places and for shorter periods than those for which precipitation records are available.

SOIL TYPES AND WHEAT PRODUCTION

As stated before (p. 7), wheat is the predominant crop on hard lands and sorghum on the more sandy lands. It is generally recognized that the certainty of wheat production is greater on soils verging on the sandy types, but that the largest crops in good seasons are likely to be reaped from heavier soils. Increasing sandiness permits readier penetration of water and penetration by a given quantity to a greater depth, where it may be beyond reach of evaporation. A sandy soil makes better use of small quantities of rain than heavier soils. On the other hand, in wet years it is not capable of holding as much water within reach of crop roots.

With increase in the sandiness of the soil there is greater difficulty in obtaining stands of wheat but less danger of total failure due to drought. There is also an increasing hazard of damage by blowing, and more skill in management is required to prevent loss from that cause. When a certain degree of sandiness is reached, wheat no longer does well.

The dry-land stations, where wheat records applicable to the area were obtained, were both located on typical hard-land soils. That at Colby is classed as a silt loam and that at Garden City as a very fine sandy loam.

Wheat has been grown intermittently for many years at the United States Dry Land Field Station, Dalhart, Tex. The soil at this station is a sandy loam that is just on the verge of being too sandy for wheat

[2] COLE, J. S. Unpublished study of evaporation and yield of spring wheat,

production. In earlier years wheat was planted on some of the lighter soils at the station and failed in all but exceptionally good years. In 1926 work with wheat was started on heavier soil. Wheat does well on this soil in favorable years, but great care is necessary to prevent damage by soil blowing.

A few plots of wheat have been grown at the United States Dry Land Field Station, Tucumcari, N. Mex. The soil at this station is definitely too sandy for wheat production. Even when wheat does not meet adverse climatic conditions, it does not make a luxuriant growth and seldom produces a high yield.

SOIL MOISTURE AND WINTER WHEAT

Soil-moisture determinations on land continuously cropped to winter wheat and on land alternately cropped and fallowed were made at Colby and Garden City throughout the growing season of the wheat crop. In a previous publication Hallsted and Mathews (*8*) discussed the effect of water in the soil at seeding time on the yields of winter wheat. In the present study moisture determinations made throughout the life of the crop are utilized.

TOTAL USE OF WATER AND YIELD OF WINTER WHEAT

The value of the water in the soil at seeding time has been recognized. It is also recognized that precipitation during the life of the crop is important. The water in the soil at seeding time is the portion of the rainfall that was stored during the period between harvest and seeding time, and this is influenced by the method of soil preparation. Since no wheat crop is growing during the period of land preparation, the water in the soil at seeding time represents the precipitation for the period minus losses by evaporation, plant growth, and run-off, and in exceedingly rare cases percolation of water to depths greater than those to which the determinations reach. The latter form of loss is very rare and not likely to happen other than on fallow, except in very sandy soil. At Colby and Garden City it is doubtful whether moisture, even in fallowed land, has penetrated to a depth from which it could not be recovered by wheat. During the life of the wheat crop, there is no way of differentiating between water lost by evaporation and water transpired by the wheat crop. Loss by run-off is less serious on wheatland than on land where row crops are grown, as the growing wheat is a preventive, and the drying of the soil by the crop promotes ready penetration of water. For these reasons, the reduction in water content of the soil between seeding and harvest, plus the precipitation for that period, is considered to be the total quantity of water used by the crop. This is done with the full knowledge that not all the water lost was used by wheat. Loss by evaporation is always present under field conditions, and water so lost may well be considered to be a part of the water used.

CORRELATION BETWEEN TOTAL WATER USED AND YIELD OF WHEAT AT COLBY AND GARDEN CITY

The quantity of water used during the life of the crop (water removed from the soil plus precipitation from seeding time to harvest) and the yield of wheat obtained on three plots at Colby for 16 years

during the period 1915–34 are shown in table 1. Two of the plots were continuously cropped to wheat, one with early and the other with late plowing, and one was on fallowed land in a pair of plots alternately cropped and fallowed. The correlation coefficient was essentially the same for each method, 0.66 on late-plowed land, 0.64 on early-plowed land, and 0.64 on fallowed land. For all three plots the correlation coefficient calculated by the sums for the three plots was 0.70 ± 0.049. The correlation is of a high order but far from perfect, as is to be expected when correlating yields with a single climatic factor. An examination of the table shows why the relationship is no higher. In some cases the total quantity of water was below the quantity necessary for any production, and, on the other hand, the use of a large quantity of water did not always result in a high yield. The latter condition is not surprising when the number of things other than rainfall that affect yield is considered.

TABLE 1.—*Water used during the life of the wheat crop and yields on three plots at the Colby and Garden City branch stations for certain years during the period 1914–34* [1]

Crop year	Colby						Garden City					
	Water used			Yield per acre			Water used			Yield per acre		
	Late plowed	Early plowed	Fallowed	Late plowed	Early plowed	Fallowed	Late plowed	Early plowed	Fallowed	Late plowed	Early plowed	Fallowed
	Inches	*Inches*	*Inches*	*Bushels*	*Bushels*	*Bushels*	*Inches*	*Inches*	*Inches*	*Bushels*	*Bushels*	*Bushels*
1914	-------	-------	-------	-------	-------	-------	14.5	15.0	14.2	7	6	15
1915	20.3	21.6	23.0	9	19	20	16.6	17.0	21.5	10	10	22
1916	12.9	14.1	14.7	9	19	26	-------	-------	-------	-------	-------	-------
1917	7.2	6.8	7.5	0	0	0	-------	-------	-------	-------	-------	-------
1918	12.5	13.0	13.3	11	5	8	-------	-------	-------	-------	-------	-------
1919	17.5	17.7	17.2	26	8	14	-------	-------	-------	-------	-------	-------
1922	12.1	11.1	13.9	12	15	18	-------	-------	-------	-------	-------	-------
1924	10.6	11.7	17.9	11	9	32	11.9	14.6	14.6	14	21	23
1925	10.8	12.1	17.6	5	6	28	8.1	8.3	13.7	0	0	13
1926	8.6	8.8	10.7	2	1	13	9.0	9.5	9.4	1	2	3
1927	12.8	11.4	13.9	2	1	3	8.5	9.3	12.9	0	0	0
1928	14.3	14.9	19.5	20	18	38	-------	-------	-------	-------	-------	-------
1929	12.0	11.5	17.0	5	6	14	11.1	14.6	16.8	13	19	26
1930	16.5	16.1	20.2	27	29	43	10.3	11.1	15.7	8	15	28
1931	16.9	16.2	24.4	9	6	23	19.9	20.4	22.5	22	26	32
1932	10.9	11.8	17.4	0	6	37	12.1	13.6	18.0	2	8	28
1934	7.1	8.9	12.5	0	0	6	7.0	7.0	11.2	0	0	3

[1] The years not included in the table were omitted because the soil-moisture determinations necessary to the study were not made, or because the crop was destroyed by factors other than lack of water.

There appears to be a definite minimum quantity of water required to produce specified yields under climatic conditions like those at Colby. No paying yield was obtained during the experiments from the use of less than 10 inches of water, no yield of as much as 20 bushels per acre was obtained from less than 14 inches of water, and no yield of as much as 30 bushels per acre was obtained from less than 17 inches of water. The following equation was used for determining yield from the quantity of water: $\text{Yield} = \frac{\text{water used} - 7.13}{0.53}$. In other words, 7.13 inches of water were required before any grain was produced. Each additional 0.53 inch of water resulted in a bushel of increased yield.

The regression equations for the different plots were much the same, and the initial quantities required to produce a crop were not greatly different. Contrary to expectation, the initial quantity of water required to produce a crop was as high on fallowed land, where more of the water used by the crop was stored in the soil, as on land where wheat was grown after wheat. This indicates that no greater weight need be given to initial water content than to water falling after seeding. This does not discount the value of water in the soil at seeding time, which is a part of the total water used by the crop. When the water that falls after seeding is sufficient to meet the minimum requirement for a crop, each inch of stored water can be valued as 2 bushels of wheat. In the greater proportion of years the rainfall from seeding time to harvest closely approaches or exceeds the minimum need. This being the case, the value of water in storage at time of seeding is easily understood.

The total quantity of water used by the wheat crop, and the yields of wheat on three plots at Garden City, similar to those at Colby, are also shown in table 1. The correlation between yield and water use is 0.827 ± 0.037. The correlation is closer than at Colby, but represents a smaller number of years. The following equation was used for calculating yield from water use: $\text{Yield} = \frac{\text{water used} - 7.69}{0.50}$. Both the initial requirement and the quantity of water needed for each additional bushel of yield were much the same as at Colby.

The actual requirements to produce specified yields were also much the same as at Colby. In all years when the water use was below 10 inches, the crop failed or the yield was very low. No 20-bushel yield was produced from less than 14 inches of water. There were few high yields, but the indications are that approximately 17 inches of water are required to produce a 30-bushel yield.

Data from Hays are not used, as conditions at Hays are considerably different from those in the area under study. Enough examination of the data was made, however, to make certain that the initial requirement to produce a yield of grain was about the same as at the other stations. It was apparent, however, that high yields were obtained on lesser quantities of water at Hays than at stations in drier sections.

To make a formula of wider application, it was considered advisable to combine the data from Garden City and Colby. While the formulas developed at the two stations were somewhat different, they were not widely so, and it was felt that the greater number of observations included in the combined data would more than compensate for any slight difference in the formula. Then, too, the combined data for the two stations might well be more applicable to the area than the data for either station singly.

For the combined data from the two stations the correlation coefficient was 0.749 ± 0.033. The equation for computing yields from water use was: $\text{Yield} = \frac{\text{water used} - 7.37}{0.51}$. In other words, 7.37 inches of water were required before any grain was produced and each additional 0.51 inch of water produced a bushel of wheat.

It is recognized that such a formula is not absolute. In fact it appears apparent from the data that the relationship between water use and yield is not a straight-line regression throughout. By the

equation, estimates of yield are too high for quantities of water less than 10 inches. With a use of less than 10 inches of water there is a falling off of yield much greater than is indicated by a straight-line regression. Either 10 inches of water is approximately the lowest quantity that will produce a yield of grain, or else other inhibiting factors such as high temperatures and evaporation that usually accompany low rainfall prevent the production of the crop that might theoretically be obtained from less than 10 inches of water.

The slope of the regression line is reduced by the fact that in some years yields were much below the quantity indicated by the quantity of water used, because factors other than water prevented the production of high yields. The year 1931 at Colby, when frost damage greatly reduced yields, and several years when lack of stand limited yields or too favorable conditions favored lodging might be cited as examples. In general it can be stated that wheat yields increased at the rate of approximately 3½ bushels per acre for each additional inch of water used above 10 to a maximum of 20 inches, when the crop developed without inhibiting factors other than water operating too strongly. Because the formula is based on bad as well as good years, yields in years of high production are generally estimated too low.

In work with wheat throughout the Great Plains, it has been found that differences in yield brought about by differences in initial water content generally average from 3 to 4 bushels per acre for each inch of water. In such cases the comparisons have been made between plots grown the same year and subjected to the same conditions. The more gradual slope of the regression line (2 bushels per inch of water) when different years are compared to each other is an indication of the extent to which other inhibiting factors reduce yields below the limitation placed by the water supply.

CORRELATION BETWEEN PRECIPITATION FOR JULY TO SEPTEMBER AND WATER IN THE SOIL AT SEEDING TIME AT COLBY AND GARDEN CITY

The application of results based on soil-moisture observations is limited, because of the few places where moisture determinations have been made. To make a more general application of results, a way had to be found to determine the total use of water by a crop where moisture records are not available. A study was therefore made to determine whether there was some relation between the quantity of water in the soil at seeding time and the precipitation for the period July 1 to September 30. July 1 was selected as the initial date because the crop is usually so close to maturity at that time that rains after that date are not beneficial, and the water may be stored in the soil for use of the following crop. September 30 was selected as the final date, because seeding has been done close to that date at Garden City, and late in September at Colby.

At Garden City there is a decided response to early preparation in years when early preparation is able to store water. Since, in the area covered by this study, harvest is comparatively early and there is a great opportunity for loss of moisture by weeds during the period between harvest and seeding, it was considered advisable to study the relationship between rainfall and wheat yields on land where weeds were not permitted to exhaust the moisture. For this reason only the early prepared plots are considered.

Table 2 shows the precipitation for the 3 months, July to September, and the available water stored in the soil at seeding time at Garden City and Colby. Since the study was made to determine the water storage during the period of land preparation, it was possible to include years at Garden City that were not used in other studies because the crop was destroyed by causes other than lack of moisture.

TABLE 2.—*Precipitation, July to September, and water stored in the soil at seeding time on early plowed plots of wheat at Colby and Garden City, 1910–35*

Crop year [1]	Precipitation		Water stored		Crop year [1]	Precipitation		Water stored	
	Colby	Garden City	Colby	Garden City		Colby	Garden City	Colby	Garden City
	Inches	*Inches*	*Inches*	*Inches*		*Inches*	*Inches*	*Inches*	*Inches*
1910		7.8		0.3	1924	8.9	14.5	2.3	4.9
1911		5.1		.2	1925	6.6	4.5	1.7	.4
1912		3.8		.0	1926	7.0	5.1	1.3	.4
1913		6.6		.9	1927	3.5	5.7	.0	.6
1914		[2] 7.7		.7	1928	6.6	7.0	1.3	1.2
1915	7.4	1.4	3.2	.0	1929	4.1	7.9	[3] .0	2.9
1916	11.4		3.3		1930	5.2	5.2	1.1	.9
1917	4.0		.1		1931	6.5	6.5	.7	1.1
1918	13.1		3.2		1932	4.6	7.6	[3] .0	1.6
1919	5.9		1.2		1933	5.1	5.1	.4	.2
1920	6.7		1.6		1934	9.3	9.0	2.4	.2
1922	9.3		.6		1935	2.6	1.7	.0	.0
1923	4.6	4.6	.6	.2					

[1] No soil-moisture determination was made at end of storage period, 1921.
[2] Precipitation in September after moisture determination was made is excluded.
[3] In Kansas Experiment Station Bulletin 273 the quantities of water in the soil at seeding time are given as 1.4 inches in 1929 and 1.6 in 1932. The determinations from which these data were obtained were made later than September and the water storage was from rains in October.

An examination of the figures shows that at both Colby and Garden City, water storage was definitely related to the rainfall, though not proportional. The correlation coefficient for the two factors was 0.830 ± 0.03. About 4 inches of rain were required before any water was stored. This is probably because so low a precipitation, distributed through 3 months, usually meant that the rain fell in small showers and was held so near the surface that it was lost by evaporation. For rainfalls of more than 4 inches during the 3 months, storage increased at the rate of approximately 1 inch for each 2¼ inches of rain. An arbitrary formula,

$$\text{storage} = \frac{\text{precipitation for July to September} - 4.00}{2.25},$$

was established for calculating storage from precipitation.

At each station there was 1 year when the storage was much lower than the rainfall indicated. In a few years, water was stored in excess of the quantity indicated by the precipitation. Most of the large departures are easily explainable. For example, at Garden City the storage for the crop of 1929 was 2.9 inches with a precipitation of only 7.9 inches. Crop records show that the crop in 1928 was hailed out and consequently did not use much of the heavy rainfall of the last part of June. In general, storage above the average quantity was usually the result of a concentration of moderately heavy rains during a relatively short period.

Storage much below the average occurred only once at each station, at Colby in the summer of 1921 (1922 crop year) and at Garden City during the summer of 1933 (1934 crop year). The written records

fail to show the reasons for the exceedingly small amount of storage during those years.

The number of exceptions to the rule is small, and it would appear that the formula gives a reliable way of calculating the water storage on hard land during the summer months prior to wheat seeding. Records at Woodward, Okla., show that water is stored from smaller quantities of rain on sandy land, but application of the formula is confined to heavier soils.

COMPARISONS OF CALCULATED YIELDS WITH ACTUAL YIELDS AT EXPERIMENT STATIONS

The calculated water stored during the period from harvest to seeding time plus the precipitation from October to June, inclusive, was assumed to be the quantity of water used by the crop. Such an assumption is not always correct, as in occasional years material rains fall after wheat has been injured beyond recovery by drought. The number of cases where such rains are sufficient to indicate a material yield, in years when the shortage of rain early in the season has caused the crop to fail, forms a small percentage of the whole.

The total estimated quantity of water available to the crop (the estimated storage plus precipitation from October to June, inclusive) was used as a basis for estimating yields by the formula previously noted (p. 11).

In order to be of value, a method of estimating wheat yields must have a certain degree of accuracy. It is not necessary to be able to calculate yields within 1 or 2 bushels, but one should be able to calculate the number of good years, poor to fair years, and failures with a considerable degree of accuracy.

TABLE 3.—*Data used in calculating wheat yields from precipitation and the actual and calculated yields of winter wheat on early prepared land at Colby, 1915–35, and annual precipitation for the year ended June 30*

Crop year [1]	Precipitation, July–September	Estimated storage	Precipitation, October–June	Total water available for crop	Estimated yield	Actual yield	Annual precipitation, year ended June 30
	Inches	*Inches*	*Inches*	*Inches*	*Bushels*	*Bushels*	*Inches*
1915	7.4	1.5	16.9	18.4	22	19	24.3
1916	11.4	3.3	9.5	12.8	11	19	20.9
1917	4.0	.0	7.2	7.2	0	0	11.2
1918	13.1	4.0	8.2	12.2	9	5	21.3
1919	5.9	.8	15.4	16.2	17	8	21.3
1920	6.7	1.2	15.5	16.7	18	15	22.2
1921	10.5	2.9	13.3	16.2	17	13	23.8
1922	9.3	2.4	10.9	13.3	12	15	20.2
1924	8.9	2.2	10.6	12.8	11	9	19.5
1925	6.6	1.2	10.0	11.2	8	6	16.6
1926	7.0	1.3	7.0	8.3	2	1	14.0
1927	3.5	.0	12.0	12.0	9	1	15.5
1928	6.6	1.2	13.6	14.8	15	18	20.2
1929	4.1	.0	12.1	12.1	9	6	16.2
1930	5.2	.5	14.9	15.4	16	29	20.1
1931	6.5	1.1	14.8	15.9	17	6	21.3
1932	4.6	.3	10.8	11.1	7	6	15.4
1933	5.1	.5	6.7	7.2	0	0	12.8
1934	9.3	2.4	6.0	8.4	2	0	15.3
1935	2.6	.0	8.7	8.7	3	0	11.3

[1] 1923 was omitted because a poor stand of wheat was obtained.

Table 3 shows the data used in calculating wheat yields at Colby from the precipitation and water storage. The second column shows the precipitation for the 3 months July to September, the third column the estimated quantity of water conserved from this rainfall by early cultivation, the fourth column the precipitation from October to June, inclusive, and the fifth the total quantity of water available for use by the wheat crop. This is the sum of the third and fourth columns, or the quantity of water present at seeding time, plus the precipitation during the life of the crop. The estimated yield was computed from the formula for total use of water and the yield of wheat.

The table shows that it has been possible to estimate wheat yields with a fair degree of accuracy. Actual and estimated yields show material differences in some years, but in groups of failures or near failures, poor to fair yields, and good yields, there was close agreement between actual and estimated yields. In the 5 years when the yield was estimated at 5 bushels or less, there were four total failures and one yield of 1 bushel per acre. An estimated yield of 5 bushels or less could be considered a complete failure, which confirms the statement made previously that estimates of yield obtained from less than 10 inches of water were likely to be too high. In 7 years poor to fair yields (6 to 11 bushels) were estimated. In 5 of these years the actual yield obtained was between 5 and 11 bushels. In 1 year, 1916, the actual yield was 8 bushels above the estimated yield owing to very favorable climatic conditions during the growing season. In 1 year, 1927, the actual yield was much below the estimated yield. This crop was seeded under unfavorable conditions and made a very poor fall growth. Its stand was so greatly reduced by soil blowing during the winter that it was unable to respond to more favorable conditions in the spring. In the 8 years when the yield was estimated at 12 bushels per acre or more, there were only 2 yields of less than 12 bushels per acre, the minimum being 6 bushels. This low yield was largely the result of frost injury.

The average estimated yield was slightly higher than the yield actually obtained, probably because yields were calculated for years not used in establishing the formula. The one striking feature of the calculation is the degree of exactness with which failure was estimated. In no year was a paying yield secured when the estimated yield was 5 bushels per acre or less. Other conditions sometimes prevented the full possibilities of a high water supply from being realized, but apparently other factors were not able to produce a crop when the water supply was deficient.

Actual yields lower than estimated yields are sometimes the result of too favorable conditions in the fall and early spring, inducing a heavy growth that the precipitation during the later part of the growing season is not sufficient to mature. Sometimes they are the result of heavy rains after the crop has been injured beyond recovery. Actual yields higher than the estimated are usually the result of cool weather during the time that wheat is filling.

Whether or not the formula can be found useful depends upon whether it can be applied to other localities. There were only three stations within the area, other than at Garden City, where data on rainfall and the yield of wheat after wheat on early prepared land at the same location were available. These were the old station at Amarillo, operated by the Department of Agriculture during the years

1907–19, the Panhandle Experiment Station at Goodwell, Okla., and the United States Dry Land Field Station at Dalhart, Tex. The yields for Goodwell are those of wheat after wheat reported in Panhandle Bulletin 54 (7), with subsequent data furnished by the station. The average of the plot of continuous wheat and of the plot of second-year wheat in the 3-year rotation reported in table 2 of that bulletin is used as the average yield of wheat on early preparation. The stations at Goodwell and Amarillo are located on hard soil and that at Dalhart is on a semihard soil.

The actual and the estimated yields of wheat at these three stations and Garden City are shown in table 4.

The table shows the degree of accuracy obtained in estimating yields by the formula given. There are material differences in some years, but the number of years of high yields, poor to fair yields, and failures was estimated with a strong degree of accuracy. At all stations the average of the estimated yields was higher than the average of the actual yields.

TABLE 4.—*Actual and estimated yields of winter wheat on early prepared land at four stations in the southern Great Plains for certain years during the period 1907–35*

Crop year	Amarillo		Garden City		Goodwell		Dalhart	
	Estimated yield	Actual yield	Estimated yield	Actual yield	Estimated yield	Actual yield	Estimated yield	Actual yield
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1907	14	1						
1908	13	14						
1909	9	0						
1910	7	10						
1911	16	4						
1912	11	7						
1913	2	1						
1914	10	23	14	9				
1915	17	24	17	12				
1916	8	4						
1917	4	8	5	0				
1918	3	0	6	0				
1919	18	19	14	21				
1920			8	2				
1921			19	8				
1924			16	23	16	8		
1925			2	2	0	0		
1926			5	2	19	24		
1927			3	0	0	0	0	0
1928					18	28	15	8
1929			13	20	12	10	19	25
1930			7	14	9	0	14	13
1931			25	25	18	18	16	26
1932			14	7	11	3	15	4
1933			2	0	0	0	0	0
1934			2	0	6	4	0	0
1935			2	0	4	1	0	0

The yields of wheat at Garden City prior to 1914 do not properly reflect the level of wheat production that might be expected for the locality and are not included in the table. In the early years at the station, the acreage of wheat planted in that section was small, and rabbits and other pests concentrated on the plots at the station, completely destroyed the crop in some years, and damaged it badly in others. After more wheat was grown, this difficulty diminished.

Special references might be made to injury by soil blowing, like that resulting in a low yield in 1921. Danger of damage by blowing

is always present in dry-land sections. Before experience had shown the need of preventive cultivation, blowing soil, sometimes originating on roads between plots, occasionally damaged wheat badly. In later years, roads were listed when necessary, and other preventive measures were taken. Thanks to the lessons learned in earlier years, conditions much more conducive to soil blowing than those in 1921 have been met without material damage in more recent years.

The precipitation for the year ended June 30 is nearly as good a measure of yield as calculated storage and precipitation at some stations, but at others, Amarillo, for example, it is much poorer. The reason for using the calculated storage and precipitation in this study is that a single formula can be applied to the area as a whole. Where precipitation alone is used as a basis for estimation, materially different formulas must be used for different sections of the area.

By using the formula established to calculate the storage, and adding this quantity to the precipitation from seeding to harvest, it was possible to apply a single formula at all stations and obtain closely comparable results. What the formula actually does is to write off the ineffective portion of the precipitation falling during the months of soil preparation. It is not felt that this formula is perfect. It has many and obvious defects, but it is believed that it is reasonably well adapted to all of the area covered by this particular study. As stated before, it cannot be applied to sandy soils, but it is a good basis for estimating the yields of wheat that could have been expected on hard lands during the period covered by precipitation records.

The estimated yields averaged slightly higher than the actual yields, but they formed a basis for predicting failures accurately and for separating years into those of good and poor yields with a reasonable degree of certainty. For the five stations for which records are given in tables 3 and 4 a yield of 5 bushels per acre or less was estimated in 23 crop years. In only 1 of these years did the yield exceed 2 bushels per acre, and in 17 of the years no grain was produced. For all practical purposes a calculated yield of 5 bushels or less may be considered a total failure.

In the 31 years when a yield of 12 bushels or more per acre was estimated, there was no total failure and only 11 yields of less than 12 bushels per acre. This was partly compensated for by three yields of above 12 bushels per acre when fair yields were estimated. There were 17 estimated yields within the range of 6 to 11 bushels. There were 15 actual yields within this range. Total failures occurred in 3 years when poor to fair yields were estimated.

It is believed that the number of estimated yields of 5 bushels per acre or less fairly represents the number of complete or nearly complete failures from drought that may be expected. In addition there will be occasional failures from causes other than drought. With calculated yields above 5 bushels per acre, a reasonable basis for division of yields into poor to fair and good yield groups is afforded. Division into these groups is not so sharply defined as the division between failure and a crop.

The measure of accuracy in the calculated yield has been considered in some detail. This is because the accuracy or lack of accuracy of the method determines its value. Unless the method employed is accepted as a true measure, the conclusions reached are of no value.

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If the method of calculation is accepted as being accurate to a reasonable degree over a large section, the conclusions reached must be given considerable weight. It is believed that, within its limit of application, the formula gives a fair picture of the yields of winter wheat that may be expected in continuous wheat production by early preparation. Comparison of actual and estimated yields at stations where comparisons are possible indicate that average calculated yields are much more likely to be too high than too low.

ESTIMATION OF WHEAT YIELDS FROM PRECIPITATION BEFORE SEEDING AND DURING THE GROWING PERIOD

Detailed precipitation records for all stations within the area were used for the purpose of estimating wheat yields according to the method outlined heretofore (p. 11). These calculations showed the number of years of good yields, fair yields, or failure that could reasonably be expected on early prepared hard land.

Average precipitation for the stations within or near the area ranged from 21 inches at Amarillo to 12 inches at Las Animas, Colo.

In this connection it might be well to mention the fact that precipitation or crop records must be long continued to represent conditions truly. At first it was assumed that crop records at Amarillo, covering a period of 14 years, represented the conditions of the locality reasonably well. In working up the estimated yields of winter wheat, it became apparent that this period of years marked a low cycle of precipitation and was one of the lowest for wheat production in the whole series of years covered by precipitation records at Amarillo, and precipitation records at that station are continuous from 1893 to 1935.

It may be further mentioned that while a single station may have an average precipitation that is representative of a section over a period of years, it may not be a good indicator in many of the individual years. In all counties where precipitation was measured at more than one station, measurements varied widely in individual years.

This statement is illustrated by data obtained by the Soil Conservation Service within the project area near Dalhart, Tex.[3] During 1935, precipitation records were kept at 10 stations within the project area. The distance apart of the most widely separated of the stations did not exceed 10 miles, yet the precipitation varied from 16.46 inches to 9.65 inches. Such a wide fluctuation within a distance of a few miles shows that for a given year a single station may not truly represent the area in which it is located. These local differences generally disappear in a long-time average.

The calculated yields for each station were studied along with the precipitation records, and when it was apparent that heavy rains had fallen too late to benefit a crop, or that precipitation was such that it would have been impossible to obtain a stand of wheat, the yield was discounted accordingly. The estimated yields at all the individual stations would require too much space for presentation, hence the detailed data for the different stations are not given.

The greater the proportion of the year's precipitation that fell during the period July to September, the lower the yield from a given quan-

[3] Unpublished records of Soil Conservation Service.

tity of rain was likely to be, provided that the smaller rainfall was sufficient to give wheat a fair start. On the face of it, this might appear to contradict the findings of Hallsted and Mathews (*8*), and of Finnell (*6*), that water in the soil at seeding time was important. If only a given quantity of rain fell each year this would be true. But as a matter of fact, the rainfall during the growing season is at least as likely to be good following a summer of high rainfall as following one of low rainfall. The water at seeding time is important because it contributes water above the precipitation for the growing season. The greater the storage at seeding time, the greater the total quantity of water available for the crop will be. It is also important in that it often carries a crop through short but critical periods of drought. During the growing season a rain that wets the soil to only a few inches may be used in part by a crop. Even though none of it is used by the crop, the occurrence of the rain usually lowers the temperature enough to reduce transpiration somewhat and thus save water for the crop. Water falling during the period of storage (July to September) that does not actually enter into and become a part of the soil water is of no benefit to wheat, as no crop is growing during that period and consequently there is no use of water by the crop and no benefit of reduced transpiration as a result of the rain.

The relative precipitation that falls in the different months does not differ widely for stations within the area having a long record. Consequently differences due to distribution of rainfall do not enter into average figures, though they profoundly influence estimated yields at individual stations.

The annual estimated yields at each precipitation station were calculated from the precipitation by the formula developed and tested as explained. The stations were then grouped according to their average precipitation, and the percentage of years with good yields, fair yields, and failures in each group was determined. The tabulated results are shown in table 5.

TABLE 5.—*Percentages of good crops, poor to fair crops, and failures calculated by precipitation groups for 43 precipitation stations*

Precipitation group (inches)	Stations	Years	Frequency of crop character indicated—[1]		
			Good	Poor to fair	Failure
	Number	*Number*	*Percent*	*Percent*	*Percent*
12–12.9	1	68	7	12	81
13–14.9	7	110	19	17	64
15–15.9	5	162	21	23	56
16–16.9	8	193	26	30	44
17–17.9	9	252	38	23	39
18–18.9	5	147	45	24	31
19+	8	158	54	23	23

[1] A good crop indicates an estimated yield of more than 11 bushels per acre; a poor to fair crop an estimated yield of 6 to 11 bushels per acre; and a failure indicates a calculated yield of 5 bushels or less.

These results are for wheat grown continuously on early prepared land. They may be modified by fallow to the extent that fallow is able to provide water in excess of that provided by early preparation. It is possible that they may be further modified by contour tillage. The extent of modification through that practice would be limited by

the quantity of water contour tillage would hold, that would be lost through run-off on carefully handled land not cultivated on the contour. In dry years this should not often be a decisive factor.

For an average precipitation of less than 13 inches the percentage of failure with wheat was estimated at 81. This rainfall group was represented by a single station, Las Animas, Colo. It is outside but near the area studied, and has the longest uninterrupted precipitation record of any station in or near the area. The utter impossibility of profitably producing wheat under those rainfall conditions is fully recognized.

For the stations having an average precipitation from 13 to 14.9 inches, failure of wheat could be expected in 3 years in 5, and a good crop only one-fifth of the time. Two 1-inch rainfall groups were taken together in this group to make the number of years more comparable to the number in other groups. Wheat production with this average precipitation falls within the extremely hazardous class.

For stations in the rainfall group from 15 to 15.9 inches the number of expected failures were half or more, the greatest change between it and the preceding group being an increase in the number of fair yields and a reduction in the number of failures. There is still the expectation of a good crop only 1 year in 5.

Much of the expansion in wheat production has taken place in locations represented by the next two higher precipitation groups, and for this reason these groups should be closely examined.

At stations with precipitation averaging 16 to 16.9 inches, failure could still be expected in more than 2 of 5 years. The number of good crops, however, increased to 1 in 4.

An average precipitation of 17 to 17.9 inches was characterized by a sharp increase in the percentage of good crops. This was brought about by decrease in the number of years of fair crops as well as in the number of failures. The number of years of expected failures remained at nearly 2 in 5, but higher returns might be looked for in the good years.

The group of stations with average precipitation from 18 to 18.9 inches is located in the portion of the area where an increase in wheat production was under way prior to 1920. In this area the number of failures to be expected from drought was approximately 3 in 10, but the percentage of expected years of good crops was further increased.

For stations with average precipitation above 19 inches there was still nearly one failure in 4 years indicated, but the number of years of good yields was increased.

It is probable that the number of years of failure shown in the higher precipitation group may be too low rather than too high. The failures shown in this table are those due to a lack of water sufficient to produce a crop. Failures from other causes are not included. The smaller the number of failures from lack of water, the greater is the percentage increase in failure that may be expected from other causes.

It is believed that the data in table 5 fairly represent the number of good crops, poor to fair crops, and failures that may be expected in this area from continuous wheat production by good methods on average hard-land soils under precipitation conditions represented by the different groups. As stated before, the method of estimate takes into consideration only those failures caused by lack of water. Esti-

mated yields in comparison with actual yields at all five stations where exact comparisons could be made averaged too high rather than too low.

SUCCESSIVE RECURRENCE OF FAILURE OF WHEAT

Single years of crop failure are serious but not disastrous. In many cases the effect of a single year's drought is mitigated by reserves of grain and feed carried over from a previous year, by reserves of soil moisture carried over by cultivation methods, or by reserves of funds received during years of good crops. Successive years of failure deplete these reserves. The more successive years of failure there are, the more critical the situation becomes. Three years of failure with wheat occurring singly in a 10-year period might well be endured, whereas the same number occurring successively would be disastrous.

For these reasons the records of the precipitation stations were studied to determine the order in which droughts had occurred. It is recognized that for stations having a short record, whether or not failures occurred successively was to a large extent accidental. By averaging all the stations in a rainfall group, however, it was felt that a fairly reliable figure could be obtained. The percentage of failures occurring singly and in groups of 2, 3, or 4, or more years in the different rainfall groups is given in table 6. The percentage of failures for more than 2 successive years may be too high, as practically all the rainfall stations include the 3 years 1933–35, which were all years of failure at many stations.

The percentage of failures, as shown in table 6, varies inversely with the precipitation. It is further shown in this table that not only the number of failures but the length of failure periods increases with lowered average precipitation.

With the station in the 12- to 12.9-inch precipitation group, single years of failure intervening between crop years were very rare. In fact, 75 percent of the failures occurred in sequences of 4 or more years.

At stations having 13 to 14.9 inches of precipitation, the number of years of failure occurring singly was materially increased, and the percentage of failures occurring in groups of 4 or more years was reduced to 40. A very small increase in average precipitation was accompanied by a profound change in the number of long drought periods, but the proportion of years when successive years of failure might be expected was still very high.

TABLE 6.—*Distribution of years of estimated wheat failure by precipitation groups for 43 stations*

Precipitation group (inches)	Years	Failures	Distribution of failures of—			
			1 year	2 years	3 years	4 years or more
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
12–12.9	68	81	5	4	16	75
13–14.9	110	64	29	6	26	40
15–15.9	162	56	23	33	30	13
16–16.9	193	44	40	17	32	11
17–17.9	252	39	50	20	30	0
18–18.9	147	31	51	22	27	0
19+	158	23	72	11	17	0

At stations in the next higher precipitation group the number of single years of failure was not increased, but the number of droughts of 2 years' duration was greatly increased. There also was material reduction in the drought periods of 4 or more years.

At stations with an average precipitation of 16 to 16.9 inches two-fifths of the failures came singly, and the number of times when four or more consecutive failures occurred dropped to a low figure, but there were still a few cases.

With an average precipitation of 17 to 17.9 inches, half of the failures occurred singly, and there were no cases where 4 or more years of consecutive failure occurred.

No major change in the distribution of failures occurred in the 18- to 18.9-inch group, but the percentage of failures of 2 successive years or less increased slightly.

With an average precipitation of 19 inches or more, 72 percent of the failures occurred singly.

It may be noted that in all the groups there is a large percentage of 3 consecutive years of failure. This is probably due to the fact that so many of the stations had 3 consecutive years of failure during the period 1933–35.

The occurrence of failures in the different rainfall groups by years rather than percentages is presented in table 7. A unit of 100 years was selected, and the figures in the table show the number of failures and the probable number of times during a 100-year period that wheat growing will face the conditions indicated in the several columns of the table.

TABLE 7.—*Expectation of failures following different numbers of years of failure as determined from estimated yields at 43 stations* [1]

Precipitation group (inches)	Years of failure	Failure following crops	Failure following 1 or more years of failure	Failure following 2 or more years of failure	Failure following 3 or more years of failure
	Number	*Number*	*Number*	*Number*	*Number*
12–12.9	81	18	63	50	38
13–14.9	64	30	34	24	12
15–15.9	56	29	27	10	4
16–16.9	44	27	17	7	2
17–17.9	39	27	12	4	0
18–18.9	31	22	9	3	0
19+	23	19	4	1	0

[1] Yields determined on a basis of 100 years at each station.

The years of failure following years when a crop was produced are remarkable for their consistency. The number of such years in the lowest average precipitation group was low, because failures for several successive years were the rule, not the exception. For stations with average precipitations from 13 to 17.9 inches, the number was almost constant, though as the precipitation increased such years formed a higher and higher proportion of the failures. With precipitations of more than 18 inches, the number of failures following crops dropped slightly, but constituted a still higher percentage of the failures.

The number of successive failures decreased sharply with increasing rainfall. For example, a crop failure following at least 1 year of

failure occurred 34 times in the 13- to 14.9-inch group and only 9 times in the 18- to 18.9-inch group.

A difference of 1 inch in annual precipitation does not appear to be very large, but table 7 shows the great difference in the probable number of successive failures brought about by the difference of a single inch in average precipitations.

The number of failures that may be expected is presented for the purpose of showing the average outlook when growing wheat continuously in a section with low average precipitation. To survive failures or successive years of failure with wheat, capital in the form of cash reserves, wheat carried over, use of cultural methods to avoid failure, or use of crops other than wheat is a necessity. The table shows how frequently such reserves will be needed.

SUMMER FALLOW AS A MEANS OF INCREASING YIELDS AND REDUCING FAILURES

It has been pointed out that the severity of drought damage in a year of failure may be diminished by means of cropping practices that carry over water from one year to the next. The most obvious way of doing this is by summer fallowing. This method of wheat production sacrifices a wheat crop in one year to provide water for the next year. Other methods of cultivation such as a very wide spacing of sorghums are also used for this purpose. Summer fallowing provides the maximum amount of water practically available for producing a wheat crop, and results with it should provide a measure of the extent to which failure can be avoided by means of moisture reserves carried over from one crop year to the next.

The benefits from summer fallowing, however, cannot be obtained without incurring certain attendant risks. The use of fallowing increases the danger of soil blowing unless cultural methods that prevent it are used. A primary control lies in the method of handling the land during the fallow year. The destruction of weeds that would consume moisture, and the maintenance of a rough or ridged surface open enough to permit ready penetration of water and to check or prevent run-off are requisites. These purposes are most nearly accomplished by cultivating fallow with implements that do not pulverize the soil and that tend to leave clods and crop residues on the surface.

Implements used in the summer cultivation of fallow must do a thorough job of weed killing, so that the number of operations can be restricted. Repeated cultivations have a tendency to destroy or to bury crop residues and to break down the cloddy structure of the soil. Whenever possible, cultivation should be done when the soil is in condition to form clods. Dry cultivation of bare soils usually tends to pulverize the surface. Where fallow is properly maintained the hazard of soil blowing is not usually unduly increased, because wheat seeded on fallowed land generally makes a vigorous fall growth and forms a better winter cover than wheat grown following wheat. If the wheat does not provide the necessary protection, the soil surface offers some resistance to erosion, and there is usually enough water stored to make possible effective cultivation to prevent soil blowing.

Improperly handled summer fallow is a definite hazard. Summer fallow on which preparation starts so late that weeds have already consumed the moisture from the spring rains or on which weeds are allowed to waste moisture later in the season fails in its only purpose,

that of storing water for the next crop. In addition it introduces a very serious soil-blowing hazard, because it creates a surface susceptible to soil blowing without providing moisture for the production of a protective cover.

Fallowed land that has been cultivated correctly as to time, but with implements that pulverize the surface, is also a soil-blowing hazard. In the absence of a fall growth of wheat sufficient to form a protective cover, it is almost certain to blow unless protected by cultivation. Soils that are too sandy may be unsafe to fallow by any method.

The Soil Conservation Service is doing demonstration work on its project areas to show safe methods of handling summer fallow. The methods used include strip cropping, and cultural implements and practices that prevent run-off. Information on the safe handling of summer fallow may be found in Farmers' Bulletins 1771 (*2*) and 1797 (*4*), which were prepared in collaboration with the Soil Conservation Service.

Well-cared-for fallow has definite limitations and cannot be regarded as a cure-all under all conditions. In the first place, the water-storage capacity of the soil must be large enough to take care of the water conserved by fallow, for, to be of value, the water must be conserved within reach of crop roots. Fallowing is a waste of effort on shallow or very sandy soils, or on soils so heavy that moisture penetration and root development of wheat are inhibited, because under such conditions it is not possible to hold adequate quantities of water within reach of wheat roots.

Fallowed land cannot store material quantities of water unless there are adequate rains during the fallow year. Crops on fallowed land frequently fail following years of drought, because the fallow did not have a chance to store water. Wheat on fallowed land will usually produce a crop in the first of a series of drought years; but when successive years of drought occur, grain on fallow will often fail, because fallow did not have an opportunity to store much water. Crops on fallowed land may fail in a single year of drought when the precipitation during the life of the crop is so low that the additional quantity of water provided by fallowing is too small to meet the minimum requirements of the crop.

The ability of fallowed land to store water increases with increasing precipitation, but the value of the stored water may decrease. The value of the stored water is as great in sections of high rainfall as in sections of low rainfall in years when crops need the water, but in many years the precipitation during the life of the crop plus the quantity present at seeding time on land where crops are grown annually is adequate for maximum crop production. In such years fallowing may not increase yields. On the contrary, yields are sometimes lower on fallowed land. However, this is more often due to lodging than to a depressing effect of the fallow.

At Hays, Kans., more water has been stored in summer fallowed land than at any other field station of the Division of Dry Land Agriculture. This is due to the combination of a soil that will hold large quantities of water and a precipitation large enough to utilize much of this storage capacity in most years. Fallowing increased yields markedly in most years, but in some years it did not, because of factors other than lack of water. During the 25 years that experi-

ments have been conducted at Hays, in only 1 year, 1935, was wheat on fallowed land a complete failure. Even in the exceedingly dry year of 1934 wheat on fallowed land produced a yield of over 20 bushels per acre. It required a year of extreme drought (1934), when fallow failed to store water, followed by another year of drought to cause failure of wheat after fallow. In general, growing of wheat on fallowed land at Hays practically prevents complete failure from lack of water. The value of fallowing at Hays is limited, however, because early preparation of land for wheat may sometimes produce equally good crops.

At Colby and Garden City conditions are different from those at Hays. Both of these stations have soils with somewhat lower water-holding capacities than the soil at Hays. This has not been detrimental, as the rainfall at these stations has seldom been high enough to utilize fully the available capacity. At both of these stations, the small quantity of water stored by fallowing has definitely limited the increase in yield of wheat on fallow. In no case was there a depressing effect following fallow in good years, or a lack of response to additional water supplied by fallow, but the yield on fallowed land in some years was low because of small water storage. With a precipitation of less than 14 inches for the year ended September 30, fallowed land generally failed to store adequate water. Fallowed land stored considerably less water than at Hays, but the stored water was always beneficial. The increase in yield due to fallowing was relatively somewhat higher in proportion to the water stored than at Hays, because stored water was always helpful. The percentage increase in yield due to fallowing was much greater than at Hays, because the yield of continuous wheat was much lower.

It is reasonable to suppose that under the same conditions, but with average precipitation lower than at Garden City and Colby, the quantities of water stored by fallowing land will be smaller, and that there will be more years when fallowed soil fails to store water. The value of the water that is stored would probably be even higher than at Colby and Garden City. Under rainfall lower than at these stations, failures following fallow are likely to be more frequent, because there will be more years of low water storage and because rainfall during the life of the crop plus the stored moisture is more likely to be insufficient for the needs of the crop.

The character of the soil is an important consideration in determining the degree to which fallowing may be helpful. The deep heavy soil at Hays enabled fallow to store more water than at any other station. A soil of similar texture in a drier section of the State would have stored less water than a lighter soil, because more water would have been lost by evaporation. Evaporation is one of the chief sources of loss of water on land that is being fallowed, and the heavier the soil the greater the proportion of water that is held close to the surface and lost by evaporation. When a certain degree of heaviness in a soil is reached, the soil after being wet to a depth of only a few feet becomes practically impervious to water. The soil at the Amarillo station is an example of a soil too heavy for fallowing to promote the storage of adequate water.

A sandy loam soil may be a valuable means of storing water in a dry section and of little value in a wetter section. This is shown by

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comparison of results at Dalhart, Tex., and Woodward, Okla., where the soils are sandy loams. The annual precipitation at Dalhart is approximately 5 inches lower than at Woodward. At Dalhart both row crops and wheat show a good response to fallow. At Woodward wheat shows some response to fallow, but row crops show very little. Row crops show a poor response at Woodward because the soil is usually filled nearly to capacity at time of seeding them, even on land where they are grown every year. Wheat responds to fallowing because the period between harvest and seeding time is too short for other methods of cultivation to store quantities of water equal to that held in fallowed land. The water storage in early prepared land in many years, however, closely approaches that in fallowed land, and consequently fallowing does not greatly increase yields. The strong response to fallowing shown by both wheat and row crops at Dalhart is not because the fallowed land holds so much more water than at Woodward, but because the precipitation between harvest and seeding time is lower and other methods of cultivation do not store quantities of water equal to that in fallowed land.

The lack of storage of water with precipitation lower than 14 inches may appear incredible to those familiar with conditions in regions of winter rainfall, where material quantities of water are stored from a much lower precipitation. In the southern Great Plains, however, the greatest precipitation occurs at a time of the year when temperature and soil conditions are such as to promote a high loss of water by evaporation.

Run-off occurs at times on fallowed land, and it is probable that contour tillage will prove of much more value in the maintenance of fallow than it is in preparing the ground where a wheat crop is grown every year. On fallowed land contour furrows can be maintained during the season of the year when heavy rains are most likely to occur and can be kept open for a longer period than on cropped land.

Where the soil and rainfall are such that fallowed land is able to store water markedly in excess of land under other cultural methods, it has a definite place in the farming system. There are few places in the area where the average yield of wheat on fallowed land will be double the yield of wheat after wheat. More wheat will usually be grown from a given acreage over a series of years by continuous production of wheat on early prepared land than would be grown by an alternate fallow and crop plan. On the other hand, failures will be more complete and frequent where wheat is grown continuously, because wheat following fallow frequently produces yields in years when wheat after wheat fails. The value of fallow lies in the fact that the yields are better distributed between years, and years of complete failure are fewer.

From the standpoint of the nonresident owner, if fallowing does not double the yield it has little value because less total wheat is produced, and his returns are based on total production, and not on the sureness of production. From the standpoint of the resident owner fallowing has much to recommend it. The lessening of the number of years of failure brought about by the use of fallow is highly desirable.

The fact that so much fallowing has been poorly done is one reason why it does not meet with more favor from landowners. A poor job of fallowing, as explained previously, not only loses 1 year's crop but

does not improve crop prospects for the next year. In addition it may actually create a hazard of soil blowing.

Well-kept fallow requires timely rather than numerous operations, and necessitates the use of tools that kill weeds without pulverizing the surface. Unless one is prepared to do a good job of fallowing, it is best not to attempt it.

The extent to which fallowing has prevented failure is shown in table 8, where yields on fallowed land are compared with yields of wheat after wheat at several experiment stations.

TABLE 8.—*Yields of wheat on early prepared wheatland and on fallowed land at five stations in the southern Great Plains during the period 1907–35*

Crop year	Amarillo		Colby		Garden City		Goodwell		Dalhart	
	Early fall plowed	Fallowed	Early fall plowed	Fallowed	Early fall plowed	Fallowed	Early fall plowed	Fallowed	Early fall plowed	Fallowed
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1907	1	2								
1908	14	17								
1909	0	3								
1910										
1911	4	5								
1912	7	13								
1913	1	4								
1914	23	22			9	11				
1915	24	16	19	20	12	21				
1916	4	5	19	26	0	6				
1917	8	9	0	0	0	0				
1918	0	0	5	8	0	1				
1919	19	18	8	14	21	22				
1920			15	32	2	6				
1921			13	25	8	13				
1922			15	18	(1)	(1)				
1923			[2] 5	[2] 2	[2] 2	[2] 2				
1924			9	32	23	24				
1925			6	28	2	16				
1926			1	13	2	10	24	31		[3] 46
1927			1	3	0	0	0	0	0	2
1928			18	38	(4)	(4)	28	32	8	8
1929			6	14	20	27	10	28	25	30
1930			29	43	14	30	0	1	13	21
1931			6	23	25	31	18	14	26	40
1932			6	37	7	30	3	21	4	30
1933			0	0	0	4	0	0	0	1
1934			0	6	0	3	4	8	0	0
1935			0	0	0	0	1	4	0	0
Average	8.8	9.5	8.6	18.2	7.4	12.9	8.8	13.9	8.4	14.7

[1] 1922 omitted because plots were mixed by storm and individual plot yields were not obtained.
[2] Poor yields due to lack of stand.
[3] Not included in average.
[4] Crop destroyed by hail.

This table shows why a blanket recommendation to fallow or not to fallow cannot be made. So much depends upon the soil, rainfall, and conditions during the life of the crop, that there may be sections where fallowing will not pay at all, sections where fallowing will pay in certain years or in a certain series of years, and sections where fallow will be reasonably consistent in increasing yields.

Table 8 shows that yields were increased more by fallow at Colby than at any of the other stations. The yield on fallowed land was more than double that on early preparation. The yields from Colby are from a single plot of wheat on early prepared land compared with one adjacent plot of wheat on fallowed land. The records show the high degree of dependability of wheat on fallowed land at Colby, and

show that the use of fallow has almost eliminated successive years of failure. The only case when the yield of wheat on fallowed land did not exceed that of wheat on early plowed land, when either produced a crop, was in 1923, and in that year lack of stand on the fallowed land was probably the cause. In no case was the quantity of water stored by fallow so great that it could not be utilized to advantage.

At Garden City fallowing increased yields materially, but not so much as at Colby. The yields at Garden City included all yields of wheat on early preparation and all yields on fallowed land, as these were well distributed through the field. It is probable that the average increase to be expected on fallowed land is somewhat higher than is indicated by these figures, as in a number of the years included wheat was injured by conditions other than lack of moisture, and inclusion of these years tends to decrease the average difference between methods. While fallowing did not double the yield of wheat, it materially reduced the number of complete failures.

At Goodwell the average increase in yield due to fallowing was about the same as at Garden City. The lack of greater response to fallowing may be due in part to the type of seasons since the station has been in existence and in part to the limitations in water absorption due to soil character. In land adjacent to the plots from which the yields are reported, it was stated by Clark (*3*) that the loam soil was about 2 feet deep, and that the third foot consisted of silty clay mixed with calcareous particles that merged into caliche at a depth of approximately 4 feet. Undoubtedly this limitation in depth of the soil sometimes limits the quantity of water available to winter wheat that can be stored by fallowing. It is a fact, however, that in the years included in the table, the precipitation during the growing season for wheat was so exceedingly low in many years that it is questionable whether a deeper soil would have permitted storage of enough water to produce a crop. In 1927, when wheat on fallowed land was a total failure, the precipitation during the 9 months from October 1926 to June 1927 was only 4.9 inches. It can readily be seen that the additional quantity of water necessary to produce a paying yield of wheat was above the quantity ordinarily stored in fallowed land. Fallowing has increased the average yield nearly 60 percent but has not greatly reduced the number of failures during the period of years the experiments have been conducted at Goodwell.

Examination of precipitation records at Goodwell for the time that records have been taken indicates that in most cases years of drought have been so severe that it is questionable whether the soil was capable of storing enough water to prevent failure. The chief function of fallowing has been that of increasing yields in poor or fair years rather than in preventing complete failure.

At Dalhart the response to fallow was almost the same as at Garden City. The crop records at Dalhart of wheat grown in its present location do not go back far enough to prove how successful fallow may be in preventing failure. A study of the precipitation records during the entire time that they have been taken at Dalhart indicates that the use of fallow would have avoided complete failure in most years. It is not probable that wheat on fallowed land would have produced double the yield of wheat on early prepared land. The year 1926, when the highest yield following fallow was obtained, is omitted from the average because no wheat was grown on early prepared land.

At Amarillo, fallow was ineffective in increasing yields materially or in preventing failures. The reason lies partly in the character of the soil which is a heavy clay that becomes almost impervious to water and roots as the distance from the surface is increased. Frequently the third foot of soil was not wet after a year of fallow. When water penetrated to depths lower than 3 feet it was recovered with great difficulty by crops. Soil-moisture determinations made on land cropped to wheat showed that even when some available moisture was present in the fourth foot section of soil, little of it was contributed to the crop. Wheat occasionally fed to depths greater than 4 feet, but the quantity of water used from the fifth foot section of soil was exceedingly small. In most years little was recovered from depths greater than 3 feet.

Results from these stations indicate that if fallowing is to be effective the soil must have considerable water-holding capacity, but not be too heavy to permit ready penetration of water and plant roots. A soil that is not deep enough to permit moisture and roots to penetrate easily to a depth of 5 feet or more cannot be expected to show a full response of winter wheat to fallowing.

One evident feature of the results is the fact that the maximum benefit cannot be obtained from fallowing without keeping a portion of the land fallow in years of high production. Some of the greatest responses to fallowing are shown in dry years following years of ample precipitation. Likewise, it is true that fallowing will not entirely prevent failures, though it will make them less frequent.

ESTIMATION FROM THE PRECIPITATION OF YIELDS ON FALLOWED LAND

Studies of the precipitation and soil-moisture data at Garden City and Colby developed a formula by which it was possible to estimate from the precipitation for the year ended September 30, with a reasonable degree of accuracy, the water stored in summer-fallowed land. The formula was no storage for 10.4 inches of precipitation and 0.6 inch for each inch of precipitation in excess of that amount, with a limit of 7 inches maximum storage. After the storage was estimated, the precipitation from seeding time to harvest (October to June) was added and the yield of wheat estimated from the total by use of the same formula as for wheat following wheat.

Table 9 shows the results of this method of estimating yields on fallowed land in comparison with known yields at four experiment stations in or near the area under study.

Data for Amarillo are not included in table 9. The table is based on the presumption that land in fallow will store considerable quantities of water available to wheat, and the soil at Amarillo will not do this. On the basis of estimated storage, estimated yields would have been much higher than actual yields. However, it is obviously not just to calculate the storage of water on land not capable of storing material quantities of water.

It will be noted that while estimated and actual yields are usually of the same order, the estimated yields do not reach the extremely high levels actually obtained in some years. The formula for estimating yields is based on both good and poor years. For this reason, as stated before, yields in years of good production are generally estimated too low. Where conditions other than moisture are generally

favorable, as at Colby, the method of estimate fails to reflect the full value of fallow in increasing wheat yields.

TABLE 9.—*Actual and estimated yields of wheat on summer-fallowed land at four stations in the southern Great Plains, 1915–35*

Crop year	Garden City [1]		Colby		Goodwell		Dalhart	
	Estimated yield	Actual yield	Estimated yield	Actual yield	Estimated yield	Actual yield	Estimated yield	Actual yield
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1915	19	20	30	23				
1916	21	6	18	26				
1917	11	0	3	0				
1918	10	1	13	28				
1919	17	24	20	25				
1920	17	7	30	40				
1921	25	14	25	30				
1922			21	26				
1923	(2)	(2)	(2)	(2)				
1924	20	25	20	37				
1925	7	18	13	21				
1926	7	7	7	10	20	31	23	46
1927	7	0	9	3	4	0	6	2
1928			22	38	19	32	18	8
1929	23	31	18	14	21	28	27	30
1930	31	33	23	43	11	1	24	21
1931	29	33	26	23	25	14	24	40
1932	25	32	17	37	20	21	25	30
1933	12	5	5	0	3	0	3	1
1934	8	3	4	6	6	8	0	0
1935	0	0	3	0	8	4	0	0

[1] 1916, badly injured by rabbits; 1920 and 1921, damaged by soil blowing; 1922, plots mixed by storm; 1928, crop destroyed by hail.
[2] Omitted because of poor stand.

No effort was made to calculate yields on fallow at all of the rainfall stations, but the method was used to estimate roughly the yields on fallowed land at a few stations. The data in table 9 show that the calculation of yields is accurate enough for rough approximations. The method is used for calculating yields of wheat on fallowed land in different farming systems discussed later.

COMPARISON OF PRECIPITATION AND WHEAT YIELDS FOR THE PERIOD 1920–31 WITH LONG-TIME AVERAGES

The period 1920–31 was one of great expansion in wheat production in the area. The experience of a majority of wheat growers is limited to this period. The question arises whether yields during that period were better than can be expected over a long period.

Precipitation for all stations within the area, except Springfield, Colo., and a few outside of it, having records of more than 25 years were studied, and the long-time averages were compared to the averages for 1920 to 1931. Springfield was omitted because its precipitation record is so broken. Without exception, the period 1920–31 showed a higher precipitation than the long-time average, the difference varying from as little as 0.1 inch at Tribune to 3.5 inches at Dalhart. The average difference for the whole group was 1.3 inches.

The long-time average included the years 1933 to 1935 at nearly all stations, and these were in many cases years of drought so severe that they might not be repeated in a generation.

For this reason the period 1920–31 was also compared with the long-time record with the years following 1931 omitted from the long-time record. It was found that at two stations, Tribune, Kans., and Cheyenne Wells, Colo., the precipitation from 1920 to 1931 was slightly below the long-time average to 1931, and at one station, Richfield, Kans., it was the same. At all the other 15 stations the 1920–31 precipitation was above the long-time average. For all the stations, the average difference was 0.8 inch. This does not appear to be very great, but its importance is seen when the difference in crop production brought about by the difference of a single inch in precipitation is considered. Wheat producers in the area must base their operations on the prospect of somewhat less precipitation than occurred during the development period.

The number of failures and the number of years of successive failure for the period 1920–31, were compared with those estimated for the longer time covered by precipitation records. In these items the short period varied sharply from the longer one. At all but one station the percentage of failures was lower for the 12 years than for the long-time period, which is to be expected from difference in average precipitation.

The most striking difference between the 12-year and the long-time record was in the number of cases when 2 or more successive years of failure occurred. Not so much difference was shown at stations in the lower rainfall groups, although even in these, the proportion of successive failures was a little lower in the 12-year period than in the long-time average. The great difference was at stations in the higher rainfall groups. Not a single station having an average rainfall of more than 17 inches showed consecutive years of failure for the 12-year period, although nearly half of these stations had at least 50 percent of their failures in groups of two or more during the long-time period. What this means in wheat production is easily understood. Successive years of failure and not single failures are the great hazards in wheat production. It is apparent that wheat growers within the section must expect a greater number of successive years of failure, on the average, than was experienced during the period 1920–31.

FREQUENCY OF EXTENDED DROUGHT PERIODS

The severe drought of 1933 to 1935 raises the question of how frequently droughts of such intensity will occur. In most cases precipitation records within the area have not been kept long enough to answer this question. Local areas have had droughts comparable with the present one at various times within the period that records are available, but droughts so widespread and severe as the recent one are extremely rare. It is necessary to go back to the period beginning in 1893 to find a comparable drought period. Without doubt the year 1893 was as disastrous as any of the years of the present drought in western Kansas, as shown by records at the seven precipitation stations then in existence. This drought, according to the precipitation records, commenced in 1892, but its full force was not felt until 1893. Heavy precipitation during the last half of 1891 coupled with good rainfall in May 1892 made that year much above the average in wheat production. Low precipitation during the last half of 1892 coupled with low precipitation during the entire year of 1893 made that year one of the very worst on record. At most of the

stations within the section, the precipitation from July 1, 1892, to June 30, 1893, was lower than for any similar period since that date. The drought commencing in 1893 continued for 5 years or more at some stations, but was broken in 1894 or 1895 at others. The scattered precipitation records available for those years indicate that the period 1893–96 must have compared closely with the present drought in length and severity.

Precipitation records have not been kept for a long enough period to indicate how frequently such periods of general drought may recur, but the available records show that they are very infrequent. Local droughts of several years' duration occur much more frequently.

COMPARISON OF COMPUTED YIELDS WITH COUNTY YIELDS

For many years the Kansas State Board of Agriculture has compiled statistics on crop production in Kansas. These statistics are on a county basis and are invaluable records of the agricultural history of the counties. Winter wheat, as the major crop, has been an object of particular concern. Prior to 1911 the yields were reported on the basis of harvested acres. From 1911 on, the number of acres planted and the number harvested were both reported. In the comparisons made, the planted and not the harvested acres were used as a basis.

Yields for a county as a whole are materially different from yields from a single station. On a county-wide basis complete failure almost never occurs. There is seldom a year when a crop is not produced at some favored spot within a county. Likewise county yields never go so high as yields from a single point on a single method of soil preparation. County yields are on the basis of wheat grown by good, poor, and indifferent methods under a wide variation of soil and rainfall conditions. Local areas may be hailed out or damaged in other ways. A county yield of as much as 20 bushels per acre is rare.

Yields for the nine southwestern counties were correlated with precipitation records and were compared with the yields estimated from rainfall records within each county. A fair agreement was shown, but there were some very great discrepancies which were explained to a considerable extent by the actual county yields and the estimated yields for counties where there were two rainfall stations. In some such cases as in Kearny and Hamilton Counties the average precipitations of two stations in a county, for the length of the record, were materially different. In other cases, as in Morton County, the average precipitation at the two stations was not widely different, but the precipitation in individual years often varied considerably.

Table 10 presents the yield of wheat on early prepared land, as estimated from precipitation records at Richfield and Elkhart and the actual yields for Morton County. This county yield is based on planted acres and not harvested ones.

The striking feature of the results is the wide variation in estimated yields for the two precipitation stations in the same county. As a rule the county yield is intermediate between the two, but, as explained before, the county yield seldom goes as high or as low as the estimated yield. The table would convince one that in most years the average precipitation for the two stations would better represent the county than the precipitation for either station alone. The average of more stations in a county would no doubt show a still closer relationship.

TABLE 10.—*Estimated yields of wheat on early prepared land as calculated from precipitation for Elkhart and Richfield, and actual yields of winter wheat in Morton County, for the period 1915–35*

Crop year	Richfield	Elkhart	Morton County [1]	Crop year	Richfield	Elkhart	Morton County [1]
	Bushels	*Bushels*	*Bushels*		*Bushels*	*Bushels*	*Bushels*
1915	26	----------	15	1926	8	26	18
1916	5	----------	6	1927	1	0	0
1917	0	----------	1	1928	18	21	10
1918	4	----------	4	1929	16	8	13
1919	23	12	16	1930	3	2	3
1920	4	9	15	1931	20	17	18
1921	16	7	13	1932	8	13	6
1922	10	8	5	1933	0	0	1
1923	----------	----------	0	1934	3	2	2
1924	12	18	11	1935	0	0	0
1925	0	0	2				

[1] Yields are based on the planted acres.

It can be safely stated that the precipitation for a single station within a county is not an accurate basis for attempting to correlate county yields with precipitation in individual years. On a long-time average, a single station may adequately represent a county, but in individual years it may not do so.

This is further proved by the fact that much closer correlations are generally shown between precipitation and yields where both are recorded at experiment stations than are shown between precipitation at a single point within a county and county yields.

Many studies were made of the comparison of county wheat yields with precipitation and with calculated use of water. The calculated use of water is the amount estimated in the soil at seeding time plus the precipitation from October to June. This was divided into groups of 1 inch, regardless of year or location. If it was between 16 and 17 inches at a precipitation station for a certain year, that year was included in the 16-inch group, and the county yield for the county in which it was located was included in that group for that year. The yields by calculated water-use groups were then assembled. The year 1923 was omitted from the calculations, because that was a year when lack of stand or winter-killing caused a complete failure of wheat over practically the whole area. It would not have been omitted had not the calculated water use been concentrated into one or two groups, thus giving these particular groups an unjustifiably low yield.

The average yields for the groups by inches were then studied. It was found that the relation between water use and yield was shown by a broken rather than a straight line. A use of less than 9 inches of water was always associated with failure or near failure. After the use of 9 inches of water was reached, there was an abrupt increase in yield. With the use of from 9 to 17 inches of water the yield increased rather regularly in proportion to the quantity of water. After the use of 18 inches of water was reached, there was no further increase in yield, indicating that water was no longer the limiting factor, and that yields were decided by factors other than water.

The sudden and drastic falling off in yield when the water use dropped below the 9-inch group, indicates that this is the lowest limit to which water use can fall without resulting in failure or near failure. In 60 crop years when the water use fell below 9 inches, there was not a single yield of more than 8 bushels per acre, and more than 90 percent

of the yields were 5 bushels or less. In the group where the water use was from 11 to 12 inches more than 60 percent of the yields were over 10 bushels per acre. This indicates the narrow limits wherein the change from almost certain failure to prospects for a fair crop takes place. It further indicates that if the precipitation at a single station within a county differs by several inches from the average for the county, the single station is a poor measure of the county in that particular year.

With a large number of years included, these differences are balanced and a high degree of correlation exists between the calculated water use and the county yield. The correlation coefficient of average water-use groups with yields for the groups is 0.945 ± 0.028, which indicates how close the average relationship is.

Studies made in a similar manner with annual precipitation for the year ended June 30 and county wheat yields, showed very similar results. A precipitation of less than 13 inches almost invariably resulted in failure. A regular increase in yield as the precipitation increased was shown until nearly 25 inches was reached. Yields did not increase with increase of precipitation above 25 inches, indicating that in such cases precipitation had ceased to be a limiting factor.

As a whole the records of county yields substantiated the findings at the experiment stations.

STUDIES WITH SORGHUMS

Sorghums, chiefly varieties of milo, kafir, Sudan grass, sorgo, and hegari, are the main feed crops of the southern Great Plains. They are planted by many wheat farmers in years when winter wheat fails to survive but moisture conditions become favorable in the late spring.

Milo and kafir, in particular, and other sorghums to a lesser extent, have been grown for many years at experiment stations in the southern Great Plains. The yields show some important relations to precipitation. The relation is influenced by the nature of the soil, the variety of a crop grown, and the cultural practice used.

The first part of the discussion deals with the relation between precipitation and yields of standard varieties of milo and kafir at experiment stations. These varieties were planted in 42- to 44-inch rows at or near the optimum planting date, which was about June 1 at Garden City and June 10–15 at Dalhart. The second part deals with an application of the results to the whole area.

Choice of varieties now affords a somewhat greater chance to obtain a yield under adverse conditions than has been possible heretofore. Within the past few years Sooner (Sixty Day) milo and other short-season varieties have been released by plant breeders. These varieties are not highly productive under good conditions, or when planted at normal planting dates. When planted late, even as late as July 10–15 in the southern part of the area, they are able to mature and produce a fair crop on a relatively small supply of water. They give the farmers a chance to produce feed at a time when the chance of obtaining a crop with standard varieties is past.

During the past few years of drought, planting of sorghums in wide-spaced rows has come into wide usage. This method is discussed in a later section (p. 46).

The bulk of the crop grown is of standard varieties in conventional width rows, and experiments with these have been conducted long

enough to provide data from which the relationship of production to precipitation may be determined. The conclusions reached in the discussion may be modified to the extent that failure can be avoided by short-season varieties or newer planting practices.

SOURCES OF DATA

There are two experiment stations in the area, Dalhart and Garden City, where the Division of Dry Land Agriculture has, either independently or in cooperation with the States, obtained sorghum records over a period of many years. At each station these crops were grown under specified cultural methods that were kept as uniform as possible from year to year. Daily precipitation records were kept at points close to the experimental plots at both of these stations. Those familiar with the area know the local nature of summer showers and know that material differences in precipitation occur within relatively short distances.

As mentioned previously (p. 8), the Garden City station is on a silt loam or very fine sandy loam soil, representative of extensive portions of the area. It is a representative hard-land soil. The Dalhart station is on a sandy loam soil typical of important areas of cultivated land.

At each of the above stations from 9 to 90 one-tenth-acre plots of Dwarf Yellow milo and Western Blackhull kafir have been grown each year. Except for some duplications, each plot differs from the others in crop sequence or in the tillage method used. Individual plot records are not presented, as this particular study was made for the purpose of establishing broad general principles. Minor differences due to crop sequence or cultural practices are not considered.

The average yield of all plots on land planted to late-maturing crops the year previous was determined for the purpose of correlating yield with precipitation, except for the omission of plots where tillage methods not practical on a farm basis had been used, and plots that had been manured or fertilized. Yields following late-maturing crops were used as a basis, because they represented yields that could be obtained on land not given summer or early fall cultivation. Such yields of milo grain, kafir grain, and total weight of kafir are given in table 11. The records for the Colby station are not used in the sorghum studies, as Colby is north of the area best adapted to sorghums.

CORRELATION BETWEEN PRECIPITATION AND YIELDS OF SORGHUMS AT EXPERIMENT STATIONS

The studies with sorghums were made on the basis of precipitation alone. This was done because precipitation showed a good relationship with yield, and because soil-moisture studies with sorghums had not been continuous at Garden City.

The precipitation was assembled on a different basis than for wheat, because sorghums occupy the land at a different period of the year. Ordinarily milo and kafir are planted early in June and finish their moisture-consuming growth in September. Thus the annual precipitation for the year ended September 30 is more closely related to sorghum yields than the annual precipitation for the year ending at any other time. Preliminary studies showed this to be true.

TABLE 11.—*Precipitation for various periods and average yields of milo and kafir grain and total weight of kafir at Garden City and Dalhart, 1909–35*

GARDEN CITY

Year	Precipitation for the period—					Average yield		
	Apr. 1 to Sept. 30	May 1 to Aug. 31	July 1 to Aug. 31	Oct. 1 to Aug. 31	Oct. 1 to Sept. 30	Milo grain	Kafir	
							Grain	Total
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Bushels*	*Bushels*	*Hundredweight*
1915	20.6	15.6	8.3	24.1	26.4	--------	17	48
1916	12.7	8.7	4.1	15.2	16.4	--------	4	30
1917	14.3	10.4	6.0	15.3	16.4	--------	0	18
1918	11.4	8.6	4.2	13.2	15.2	3	3	13
1919	11.0	7.2	4.1	17.5	20.7	35	22	44
1920	16.1	12.4	6.6	16.6	19.2	35	34	72
1921	16.3	11.2	4.5	19.3	21.8	26	23	34
1922	11.2	8.5	4.5	14.7	14.7	17	17	37
1923	32.1	22.0	8.4	26.8	33.0	33	18	29
1924	9.1	5.3	2.8	13.6	15.3	36	30	52
1925	10.9	6.3	3.1	11.3	13.3	7	5	29
1926	12.0	9.9	4.6	13.9	15.1	4	8	30
1927	12.5	8.1	4.3	12.3	15.1	11	8	24
1928	25.2	23.5	7.7	27.2	27.4	51	38	68
1929	12.5	8.6	3.0	15.1	17.4	16	19	51
1930	13.5	8.2	3.2	13.2	16.6	2	1	32
1931	12.7	12.4	7.4	26.1	26.3	30	33	68
1932	13.8	11.4	4.6	17.8	18.2	7	11	36
1933	15.4	10.5	6.0	14.1	17.1	11	9	29
1934	3.9	3.2	1.3	8.7	9.0	0	0	0
1935	7.3	6.2	1.2	8.6	9.5	0	0	0

DALHART

1909	11.0	8.7	1.9	11.2	13.3	3	0	51
1910	14.3	12.8	5.8	18.6	18.6	27	24	107
1911	10.3	9.2	5.5	10.8	11.4	13	5	26
1912	14.6	10.1	4.3	17.5	19.5	34	0	58
1913	8.3	6.0	2.4	7.2	8.6	0	0	21
1914	19.2	14.9	4.0	24.1	24.4	54	42	100
1915	16.9	10.5	5.8	20.6	21.8	39	36	80
1916	13.3	11.1	6.0	15.9	16.6	10	10	42
1917	9.2	7.6	3.9	8.8	10.1	1	0	18
1918	11.6	9.3	3.2	14.7	16.1	10	13	31
1919	19.1	10.5	5.9	22.1	27.2	39	33	55
1920	15.1	14.0	3.9	18.8	19.6	30	22	57
1921	16.1	15.3	5.8	23.0	23.1	22	24	47
1922	17.6	11.9	3.5	19.7	20.2	21	13	38
1923	21.8	15.6	7.8	23.0	25.1	24	24	66
1924	12.3	9.5	6.3	21.2	22.9	19	26	50
1925	18.1	12.4	7.1	15.7	20.3	25	29	69
1926	14.6	9.7	2.0	15.4	17.4	24	23	54
1927	16.6	13.0	9.4	15.7	18.5	21	15	42
1928	18.3	17.7	8.1	19.5	19.6	31	28	47
1929	14.3	12.4	7.3	22.6	24.1	31	28	54
1930	16.6	13.5	6.4	18.7	19.4	28	29	42
1931	10.5	7.5	4.8	19.1	19.9	24	28	42
1932	16.4	13.1	2.9	17.4	19.1	10	16	31
1933	8.3	7.6	6.2	9.8	10.3	0	0	0
1934	7.6	4.8	1.8	7.7	9.6	3	4	15

The precipitation for periods of less than a year, especially during the growing season and during the period of most rapid growth of sorghum, might also be expected to be closely related to yield. Precipitations for portions of the year, as well as for the year as a whole, are presented in table 11.

The precipitations for the different periods of the year, shown in table 11, were correlated with the yields of milo and kafir, and summarized in table 12.

There was little difference in the value of the precipitation for the year ended September 30 and that for the 11 months ended August 31 as measures of the yields of sorghums. The precipitation for either period was a much better measure of yield than the precipitation for any one of the shorter periods studied.

TABLE 12.—*Coefficients of correlation between the yields of grain sorghums and the precipitation for different periods at Garden City and Dalhart*

Station and item	Correlation with precipitation for—				
	Year ended Sept. 30	Oct. 1 to Aug. 31	Apr. 1 to Sept. 30	May 1 to Aug. 31	July 1 to Aug. 31
Garden City:					
Yield of milo, grain	0.74±0.07	0.76±0.07	0.57±0.11	0.62±0.10	0.64±0.09
Yield of kafir, grain	.63± .09	.68± .08	.41± .12	.59± .10	.52± .11
Yield of kafir, total	.60± .09	.65± .08	.39± .12	.47± .11	.56± .10
Dalhart:					
Yield of milo, grain	.81± .05	.82± .04	.74± .06	.60± .08	.35± .12
Yield of kafir, grain	.83± .04	.83± .04	.71± .07	.60± .08	.41± .11
Yield of kafir, total	.66± .07	.67± .07	.64± .08	.54± .09	.22± .13

Regression equations were calculated from the 12-month precipitation totals and the yields in table 11. A very low yield or failure could be expected at Garden City when the precipitation was less than 13 inches and at Dalhart when it was less than 12 inches. The lower precipitation required to produce a yield at Dalhart represents without doubt a real difference due to the more sandy nature of the soil. Much of the precipitation used in producing a sorghum crop falls during the summer. A given quantity of water penetrates to a greater depth on sandy than on hard soil, and less is held near the surface to be quickly lost by evaporation, consequently less is required to produce a yield of sorghum. It is also true that yields of sorghum are obtained from still less total water on soils containing greater percentages of sand than the soil at Dalhart. However, the soils at Dalhart and Garden City represent most of the agricultural soils within the area, and conclusions will be based on results from these stations.

As with wheat, there appears to be a fairly well-defined lower limit of precipitation below which a fair crop of grain will not be produced. High quantities of rain were not always effective in producing high yields.

The actual yields of kafir grain, and the yields estimated from the regression formulas for Garden City and Dalhart are shown in table 13. In most cases it will be noted that estimated yields are within 10 bushels of the actual yields. The widest variations are at Garden City in 1923 when the actual yield was 40 bushels below the estimated yield, and in 1924 when it was 23 bushels above. There are two reasons for the low actual yield in 1923: (1) A hailstorm on August 4 damaged kafir so severely that it did not fully recover, and (2) the precipitation was too heavy for all of it to be used by the damaged crop. The high yield in 1924 was due to a carrying over of moisture from 1923. The rainfall for September 1923 was more than 6 inches, and the soil must have held a large amount of available water when the 1923 crop matured. Enough soil moisture was stored to be the chief factor in producing the good yield in 1924.

One would expect estimated and actual yields to approximate each other at the stations from whose yields the formulas were derived. The real test of such a formula is to apply it to other locations. In such applications, difference in soil texture must be taken into consideration, as it would not be fair to apply the Garden City formula to sandy loam soils, or the Dalhart formula to silt or clay loam soils.

TABLE 13.—*Actual and estimated yields of kafir from precipitation at Garden City, 1915–35, and Dalhart, 1909–35*

Year	Garden City				Dalhart			
	Precipitation [1]	Actual yield	Estimated yield	Difference	Precipitation [1]	Actual yield	Estimated yield	Difference
	Inches	*Bushels*	*Bushels*	*Bushels*	*Inches*	*Bushels*	*Bushels*	*Bushels*
1909					13.3	0	7	−7
1910					18.6	24	19	+5
1911					11.4	5	3	+2
1912					19.5	0	21	−21
1913					8.6	0	0	0
1914					24.4	42	31	+11
1915	26.4	17	39	−22	21.8	36	26	+10
1916	16.4	4	10	−6	16.6	10	15	−5
1917	16.4	0	10	−10	10.1	0	1	−1
1918	15.2	3	7	−4	16.1	13	13	0
1919	20.7	22	23	−1	27.2	33	37	−4
1920	19.2	34	18	+16	19.6	22	21	+1
1921	21.8	23	26	−3	23.1	24	29	−5
1922	14.7	17	6	+11	20.2	13	22	−9
1923	33.0	18	58	−40	25.1	24	33	−9
1924	15.3	30	7	+23	22.9	26	28	−2
1925	13.3	5	1	+4	20.3	29	22	+7
1926	15.1	8	7	+1	17.4	23	16	+7
1927	15.1	8	7	+1	18.5	15	19	−4
1928	27.4	38	42	−4	19.6	28	21	+7
1929	17.4	19	13	+6	24.1	28	31	−3
1930	16.6	1	11	−10	19.4	29	21	+8
1931	26.3	33	39	−6	19.9	28	22	+6
1932	18.2	11	16	−5	19.1	16	20	−4
1933	17.1	9	12	−3	10.3	0	1	−1
1934	9.0	0	0	0	9.6	4	0	+4
1935	9.5	0	0	0				
Average	18.3	14.3	16.7		18.3	18.2	18.4	

[1] Year ended September 30.

Crop yields were obtained at Amarillo, Tex., during the period 1907–19, at Goodwell, Okla., during the period 1925–34, and at Tribune, Kans.,[4] during the period 1921–35 under soil conditions somewhat similar to those at Garden City. The yields from Amarillo were obtained under the same tillage practices as those at Garden City and Dalhart. Yields from Tribune are averages of several varieties of milo and kafir. The yields for Goodwell are those reported for milo (7). Table 14 shows the precipitation and the actual yields at Amarillo, Goodwell, and Tribune, and the yields for those stations as calculated from the formula based on Garden City data. The table indicates that the formula derived from Garden City data can be applied to similar types of soil in other parts of the area.

From the evidence presented it appears that the annual precipitation for the year ended September 30 is a fair indicator of sorghum yields. It is possible to estimate from precipitation records the yields over the entire period for which such records are available.

[4] Unpublished data furnished by the station.

If past precipitation records are a fair measure of what may be expected in the future, this gives a means of estimating future possibilities of growing sorghums in the area wherever precipitation covering a representative number of years is available.

TABLE 14.—*Actual and estimated yields from precipitation data by the formula from Garden City data*

Year	Precipitation, year ended Sept. 30	Milo			Kafir		
		Actual yield	Estimated yield	Error of estimate	Actual yield	Estimated yield	Error of estimate
	Inches	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
AMARILLO, TEX.							
1907	19.9	24	22	+2	12	18	−6
1908	21.3	37	24	+13	29	24	+5
1909	15.5	5	13	−8	3	8	−5
1910	15.6	20	13	+7	13	8	+5
1911	24.9	28	31	+3	17	35	−18
1912	16.9	27	16	+11			
1913	14.7	0	12	−12	0	6	−6
1914	16.6	23	15	+8	11	11	0
1915	28.6	45	38	−7	24	45	−21
1916	14.2	4	10	−6	6	4	+2
1917	18.2	15	18	−3	7	16	−9
1918	11.8	3	6	−3	0	0	0
1919	26.4	42	34	+8	26	39	−13
Average	18.8	21	19.4		12.3	17.8	
GOODWELL, OKLA.							
1925	15.2	4	12	−8			
1926	18.0	15	18	−3			
1927	16.9	24	16	8			
1928	18.3	20	18	2			
1929	21.1	23	24	−1			
1930	16.5	17	15	2			
1931	18.8	7	19	−12			
1932	15.6	7	13	−6			
1933	11.7	15	6	9			
1934	14.5	1	11	−10			
Average	16.7	13.3	15.2				
TRIBUNE, KANS.[1]							
1921	16.8	17	15	2	17	12	5
1922	16.1	20	14	6	20	10	10
1923	23.0	23	28	−5	23	30	−7
1924	20.6	16	23	7	16	23	7
1925	13.4	15	9	6	15	2	13
1926	10.2	1	3	−2	1	0	1
1927	12.9	3	8	−5	3	1	2
1928	19.0	20	20	0	20	18	2
1929	17.8	12	17	−5	12	15	−3
1930	12.8	11	8	3	11	1	10
1931	13.5	19	9	10	19	3	16
1932	19.9	10	21	−11	10	21	−11
1933	16.2	11	14	−3	11	10	1
1934	8.6	0	0	0	0	0	0
1935	8.8	0	0	0	0	0	0
Average	15.3	11.8	12.6		11.8	9.7	

[1] Actual yields are the averages of milo and kafir.

CORRELATION BETWEEN PRECIPITATION AND YIELDS OF SORGHUMS ON FALLOWED LAND

Milo and kafir have been grown on fallowed land at Garden City and Dalhart for many years. Fallowing for row crops presents a different problem than fallowing for wheat. With wheat, the land to be fallowed goes through the first winter in grain or row-crop stubble; it is fallowed during the summer and planted to wheat in the fall. Generally the wheat makes an adequate winter cover. Where land is fallowed for row crops, after being kept fallowed during the summer it must be left bare over winter. This introduces a danger of soil blowing greater than that on land fallowed and planted to wheat. However, during the period of study at Garden City and Dalhart, the moisture condition of the soil was generally such that a minor amount of preventive cultivation was sufficient to hold the soil in place during the winter.

There must be a large increase in acre yields to pay for fallowing. Less labor and expense are required to keep a portion of the land in fallow and a portion in sorghum than is required when all the land is cropped, hence the yield need not be twice as high on fallow to make fallowing for the crop practicable, if wind erosion can be cheaply controlled during the fallow period.

The actual increase in yields of sorghum grain that may be harvested is not adequately shown by a comparison of plot yields on continuously cropped and on fallowed land. Frequently sorghum on fallowed land produces large heads that may be easily harvested in years when sorghum after sorghum produces small heads that are so expensive to gather that only a few of the larger ones are harvested. The difference in the grain yield that would actually be harvested under farm conditions is more in favor of fallow than that indicated by average yields.

The extent to which fallowing has increased acre yields of sorghum and the extent to which it has avoided crop failure, is shown in table 15, in which the yields of sorghums on fallowed land are compared with those on cropped land at Dalhart and Garden City.

At Dalhart, the grain yield of sorghums was increased about 50 percent by fallowing. This means that considerably less sorghum would have been grown under an alternate fallow and crop plan than would have been grown by planting sorghum on cropped land. However, there was not a single year from the time experiments were started until 1933 when milo on fallowed land did not produce a yield of 10 or more bushels per acre. During the same period there were 3 years when milo grown after crops produced yields of less than 10 bushels per acre; in most cases yields that would not have paid for harvesting.

It might be pointed out that there were no failures or low yields of sorghum after sorghum at Dalhart during the period 1920–31. The precipitation for this period was practically 3 inches above the average for all years. How soon such a series of years will recur is not known. If average precipitation is a measure of what may be expected to occur in the future, periods so favorable to continuous cropping may be expected to be rare.

TABLE 15.—*Comparative yields of sorghums after fallow and after crops at Dalhart and Garden City*

Year	Dalhart							Garden City						
	Precipitation[1]	Milo		Kafir		Kafir (total)		Precipitation[1]	Milo		Kafir		Kafir (total)	
		After crop	After fallow	After crop	After fallow	After crop	After fallow		After crop	After fallow	After crop	After fallow	After crop	After fallow
	In.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Cwt.*	*Cwt.*	*In.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Cwt.*	*Cwt.*
1909	13.3	3	15	0	0	51	93	------	------	------	------	------	------	------
1910	18.6	27	69	24	76	107	228	------	------	------	------	------	------	------
1911	11.4	13	28	5	23	26	120	------	------	------	------	------	------	------
1912	19.5	34	52	0	30	58	113	------	------	------	------	------	------	------
1913	8.6	0	10	0	21	21	73	------	------	------	------	------	------	------
1914	24.4	54	45	42	38	100	85	------	------	------	------	------	------	------
1915	21.8	39	40	36	51	80	99	26.4	------	------	25	26	55	51
1916	16.6	10	25	10	22	42	78	16.4	------	------	3	9	24	36
1917	10.1	1	17	0	6	18	24	16.4	------	------	0	11	20	45
1918	16.1	10	19	13	14	31	33	15.2	3	6	3	7	14	30
1919	27.2	39	41	33	26	55	47	20.7	35	43	23	24	40	50
1920	19.6	30	19	22	20	57	50	19.2	35	77	30	45	63	101
1921	23.1	22	33	24	25	47	61	21.8	26	40	20	22	35	41
1922	20.2	21	19	13	19	38	54	14.7	17	31	16	31	36	50
1923	25.1	24	29	24	28	66	87	33.0	33	40	21	26	34	39
1924	22.9	19	27	26	32	50	67	15.3	36	59	31	47	51	76
1925	20.3	25	44	29	40	69	108	13.3	7	35	9	32	34	79
1926	17.4	24	34	23	31	54	73	15.1	4	14	7	17	34	55
1927	18.5	21	45	15	8	42	49	15.1	11	30	9	26	28	55
1928	19.6	31	53	28	36	47	64	27.4	51	65	41	52	76	104
1929	24.1	31	58	28	30	54	68	17.4	16	45	23	52	58	97
1930	19.4	28	51	29	31	42	52	16.6	2	16	6	19	39	68
1931	19.9	24	44	28	34	42	56	26.3	30	55	34	48	76	98
1932	19.1	10	32	16	18	31	43	18.2	7	33	15	24	44	39
1933	10.3	0	0	0	0	0	0	17.1	11	29	12	18	34	54
1934	9.6	3	2	4	4	15	19	9.0	0	0	0	0	0	0
1935	------	------	------	------	------	------	------	9.5	0	0	0	0	0	0
Average	18.3	21	33	18	26	48	71	18.3	18	34	16	26	38	56

[1] Year ended September 30.

Fallowing at Garden City increased the average grain yield by about 75 percent. It was much more important in preventing failure than at Dalhart. This was not due to a greater yield on fallow than at Dalhart, but to more frequent failures on land that had been cropped. Fallow did not entirely prevent low yields even prior to 1933, but it materially reduced the number of them.

The relation of yields following fallow to rainfall is, of course, not so simple as in the case of continuous cropping. Two important reasons for this may be pointed out: (1) Crops on fallowed land sometimes have enough moisture to cause some other factor to be limiting; and (2) the quantity of water stored by fallow depends upon a number of factors such as the texture, structure, and surface conditions of the soil, the nature of the precipitation, the freedom of fallow from weeds, and the severity of climatic factors other than precipitation.

It seems logical that yields on fallowed land should be related to precipitation of the year the crop was grown, and also to precipitation of the year previous, or the fallow year. The extent to which this is true is shown in table 16. At both stations there is a definite but not close relationship of precipitation during the crop year and the yield. At Garden City there is a faint relation of yield to precipitation during the fallow year, but at Dalhart there is apparently little relation between the two. The reason for the lack of relationship at Dalhart is shown by the soil-moisture data for the station. In all but a very

few cases the precipitation during the fallow year was sufficient to wet the soil in the fallowed plot to its field-carrying capacity. Since an equal degree of wetness was produced by varying quantities of precipitation, it is apparent that the exact quantity of rain during the fallow year could have had little influence upon the yield. Soil-moisture records on milo are not available at Garden City, but it appears reasonable that the heavier soil at that station, with its higher water-holding capacity, was not filled in many of the years. Thus there should be some relationship between precipitation and quantity of water conserved.

TABLE 16.—*Relation of the crop year's* [1] *precipitation and the fallow year's precipitation to milo and kafir yields on fallowed land at Garden City and Dalhart*

Item	Garden City			Dalhart		
	Milo grain	Kafir		Milo grain	Kafir	
		Grain	Total		Grain	Total
Coefficients of correlation:						
Yield and crop year's rainfall	0.618	0.489	0.408	0.621	0.503	0.336
Probable error	.098	.112	.123	.080	.098	.117
Yield and fallow year's rainfall	.431	.387	.271	−.004	−.099	−.099
Probable error	.130	.125	.136	.132	.131	.131
Combination or multiple	.759	.605	.537			
Average precipitation ... inches	18.3	18.3	18.3	18.3	18.3	18.3
Average yield ... bushels or hundredweight	34.0	26.0	56.0	33.0	26.0	71.0
Comparable average yield after crops, bushels or hundredweight	18.0	16.0	38.0	21.0	18.0	48.0

[1] Precipitation from October 1 to September 30.

Table 16 shows that at Garden City a multiple correlation of the yield with the precipitation for the fallow year and the crop year is much higher than the correlation with the precipitation for either year alone, which shows that differences in quantities of water stored during the fallow year are a factor in determining yields.

APPLICATION OF RESULTS

As previously stated, the object of this study is to determine as nearly as possible the reliability of the production of different crops in the area. The close relationship of sorghum yields to precipitation makes it possible to use precipitation data in estimating past and thus possible future yields throughout the area.

Records from all cooperative Weather Bureau stations within the area, from the time they were established until October 1, 1935, were tabulated as annual precipitation for the years ended September 30.

The years were then classified into groups according to precipitation for the 25-year period 1911–35, as this period appeared to represent average conditions. Only the stations with 25-year records were used. At Dalhart and Garden City yields seem to fall naturally into certain precipitation groups. The groupings shown in table 17 were made according to these natural divisions in yield. On the basis of these yields the following assumptions regarding the different groups were made:

Group A.—Good, over 20 bushels of grain per acre. A farmer in most years can realize a good profit on such yields.

Group B.—Poor to fair, 10 to 20 bushels per acre. A yield in this group on all acres planted will at least pay for harvesting and will usually allow the farmer a small profit above his total cost of producing a crop, including his own labor. The yield of forage obtained would be more than 1½ tons per acre.

TABLE 17.—*Key to classification of crop years at the various points where precipitation is recorded, based on the average yields of milo and kafir following either wheat or row crops at Garden City and Dalhart*

Group	Rank	Yield per acre	Precipitation (Garden City formula) (inches)	Precipitation (Dalhart formula) (inches)
A	Good	More than 20 bushels	More than 19.4	More than 18.5.
B	Poor to fair	10 to 20 bushels	16.0 to 19.4	14.1 to 18.5.
C	Forage only	Less than 10 bushels, but more than 1,000 pounds of forage.	11.2 to 15.9	9.1 to 14.0.
D	Pasture or none	Less than 1,000 pounds, total	Less than 11.2	Less than 9.1.

Group C.—Forage only, less than 10 bushels of grain, but more than 1,000 pounds of forage per acre. The grain would probably not pay to harvest, but the forage would be worth cutting. Some of the larger heads might be harvested.

Group D.—Pasture or none. Total crop failure or small yields of forage not worth cutting.

Table 18 shows the percentage of estimated yields at stations with different average precipitation that have fallen within the different yield groups, and how the expected yields of sorghums vary with the soil type as well as with the precipitation. Sandy loam soils are represented by Dalhart and silt loams and clay loam soils by Garden City.

TABLE 18.—*Percentages of sorghum yields falling in the several yield groups as estimated from precipitation for 21 stations in the southern Great Plains during the period 1911–35*

Average precipitation [1] (inches)	Yields calculated for Dalhart basis				Yields calculated for Garden City basis			
	Group A	Group B	Group C	Group D	Group A	Group B	Group C	Group D
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
12–12.9	12	16	56	16	8	12	36	44
14–14.9	20	40	32	8	8	36	40	16
15–15.9	22	38	34	6	14	30	43	14
16–16.9	26	43	27	4	18	37	33	12
17–17.9	44	31	24	1	36	27	28	9
18–18.9	52	28	16	3	44	29	17	9
19	54	31	15	0	44	31	21	4

[1] There were no stations with 13 inches average precipitation.

The different precipitation groups are represented by from one to five stations each. The two lowest precipitation groups are represented by single stations. All the others are averages of three or more stations, and the results are probably more representative than those for a single station.

The most striking difference between soil types is in the number of complete failures, as represented by the D group. The danger of complete failures was no greater under a 14- to 14.9-inch average precipitation on sandy soil than it was on an 18- to 18.9-inch average precipitation on heavy soil.

Throughout the range of average precipitations, the number of years when yields of more than 10 bushels per acre could be expected was materially higher on sandy than on heavier soils. This is in line with farm experience and is of course the basis for the predominance of row-crop production on the lighter soils.

While few comparable records are available, yields from the Clayton, N. Mex., State station [5] make it appear certain that yields are obtained there on very sandy lands on smaller quantities of precipitation than at Dalhart. With an increase in sandiness, however, there is an increased difficulty in obtaining stands, and a greater danger of wind erosion during the winter and spring months. A tall stubble to help hold the soil in place is almost a necessity on soils of this type. In good years very sandy soils are not likely to be so productive as sandy loam soils.

The gradual increase in the percentage of good crops with increasing average precipitation is apparent on both types of soil. The corresponding decrease in the number of poor yields or failures is equally evident.

The large number of low yields or failures on hard land in the lower average precipitation groups makes it apparent that in localities with such precipitation sorghums must be grown more for fodder than for grain. On hard lands, where the average precipitation is less than 16 inches, low yields or failure may be expected in fully half the years. This does not mean that no grain would be produced in these years, but that fields as a whole would not be harvested, except for feed. In most years the larger heads would probably be harvested for grain.

The use of fallow would undoubtedly result in many more years of fair or good yields under average precipitations of 15 inches or more. With less than 15 inches it is probable that the limitation in the quantity of water that could be stored by fallowing would reduce its assurance of a crop.

As mentioned previously, fallowing a very sandy soil is relatively ineffective, because the soil is not capable of holding much water within the zone occupied by crop roots. Fallowing such a soil for sorghum might be disastrous, because sandy soil when not protected by a crop or crop residue is likely to suffer wind erosion during the winter.

COMPARISON OF PRECIPITATION AND SORGHUM YIELDS FOR THE PERIOD 1920–31 WITH LONG-TIME AVERAGES

The estimated yields for the years 1920–31 show some interesting results when compared with longer records. This period was compared with the 25-year period, 1911–35, and, at the stations where it was available, with the 44-year period, 1892–1935. It is quite striking that estimated yields at all but 2 of the 21 precipitation stations were much better during the period 1920–31 than during the 25-year period. Yields were much above the long-time average, and the number of failures or low yields were much below the average.

Records for 44 years were available for only eight stations. Two of these were made by combining the records for two nearby stations. In every case the precipitation for the 44-year period was much lower

[5] Unpublished data furnished by the station.

than for the 12-year period. At all but one station it closely resembled that for the 25-year period. The average precipitation at the eight stations during the 44-year period was approximately 0.1 inch lower than that of the same stations for the 25-year period, and 1.4 inches lower than that of the same stations during the 12-year period. Evidently conditions during the period of rapid development were better than the average that can be expected during a long period. Sound farming in the area will require greater reserves of feed carried over from one year to another as bundle feed or silage than were required during the 12-year period.

WHEAT AND SORGHUM PRODUCTION

The foregoing discussions of wheat and sorghums show the yields of these crops which may be expected under different rainfall conditions. Both of these crops in the area under study are dependent upon the rainfall, and the percentage of good crops increases with increases in the average rainfall and the percentage of failures decreases.

Complete failures are much more frequent with wheat than with sorghums. As a rule, sorghum will produce at least a feed crop in years when wheat fails. In some years sorghums make high yields when wheat has failed, but such years are the exception rather than the rule. They are the result of rains that fall too late to benefit the wheat but early enough to benefit sorghums. Of course, in such years precipitation during the life of the sorghum crop must be above normal. Had the precipitation been high enough to store any considerable quantity of water before the sorghum was planted, the chances are that wheat would not have failed.

Farmers frequently assume that it is always possible to produce a crop of sorghums when wheat fails. This is not altogether true. While complete failures with sorghums are infrequent, practically all of them are recorded in years when wheat has also failed. It is also true that the percentage of sorghum crops producing a low yield of grain, or forage only, is much greater in years when wheat fails than in years when early precipitation has been sufficient to produce a wheat crop. If grain sorghums are to be grown as a feed, a more certain supply can be obtained by planting some sorghum each year and carrying over a supply from good years than by attempting to grow sorghum chiefly in years when wheat fails.

Comparison of tables 5 and 18 shows the probable yields of wheat and sorghum that may be expected in the different groups of average precipitation. Since sorghums are normally grown principally on land too sandy for wheat, the comparison should be confined to the sorghums grown on heavier land. It is on the heavier land where wheat is most widely grown, that the need for avoidance of complete failure through the growth of other crops is greatest. The extent to which this may have been accomplished in past years is indicated by the estimated yields of the two crops under similar precipitation.

In the 18- to 18.9-inch precipitation group, wheat may be expected to fail because of drought, or to produce a crop too small to harvest, approximately 3 years in 10. Under the same precipitation sorghum will fail to produce a feed or grain crop less than 1 year in 10. The

increase in total failures brought about by decreasing precipitation is much more rapid with wheat than with sorghums. Under a 15- to 15.9-inch average precipitation, wheat on hard land may be expected to fail fully half of the time, but sorghums only about one-seventh of the time. There will, however, be about 4 additional years in 10 when the grain yield of sorghums will be less than 10 bushels per acre.

The fact that grain sorghums are less likely to produce grain in years when, or in sections where, the precipitation is so low that wheat fails, points to the fact that as precipitation decreases and wheat fails more frequently it is more necessary to depend upon sorghums as a forage rather than a grain crop.

Sorghums are far less subject to total failure than wheat, even on hard lands. Their growth, however, sometimes requires labor at a time when it is required for wheat, so a wide extension of acreage on hard lands is not advisable or desirable. There is little doubt, however, but that an acreage of sorghums from year to year sufficient to furnish supplemental forage and feed for a farm herd is essential to a stabilized agriculture. Reserves of feed from sorghums carried over into the present drought cycle materially helped many farmers through trying years. In all too many cases no feed reserves were available, and when complete failure came it brought the necessity of sacrificing all of the farm herd, or buying feed at prohibitive prices. A trench silo filled during a good year and held until absolutely needed, would have saved at least a portion of many farm herds.

Droughts of the length and severity of the present one do not occur often. But local droughts of 1 to several years' duration occur at intervals. Stable agriculture in the area must be based on the prospects of more frequent failures or low yields of both wheat and sorghums than was experienced during the period from 1920 to 1931.

As has been stated, wheat and sorghums are the major crops in the area. The question then arises as to the proper way or rotation to grow them. Results at the dry-land field stations show that the yield of sorghum after wheat is generally a little higher than following sorghums. On the other hand, sorghum is a poor preparation for wheat. The sorghum grows until late in the fall, and unless there are ample fall rains, the land has little opportunity to store moisture before wheat is seeded. The yields of wheat after sorghums are much lower than following wheat. The two crops do not fit well into a direct rotation with each other.

An alternative is to fallow after the sorghum and plant the wheat on fallow. In sections and with soils where fallowing materially increases yields, going from sorghum to wheat by means of fallow would appear to be the logical way of handling the matter. Where such a rotation is desirable, the Soil Conservation Service recommends that the field be arranged in long narrow strips on the contour as a protection from wind erosion. Where fallowing does not materially increase yields the cost is unjustifiably high.

The wide spacing of sorghums as a preparation for wheat is a subject that has been much discussed, but upon which there is little direct experimental evidence. The actual yields of sorghum in double-spaced rows have been widely tested. The results reported by Martin and Sieglinger (*11*) indicate that the yields of milo are very little lower on double-spaced than on single-spaced rows. Yields of kafir are decreased approximately 10 percent by double spacing. Results with

triple-spaced milo rows are available at only one station for a period of only 8 years. These results indicate that milo in double-spaced rows will produce higher yields of grain than in triple-spaced rows during years of good production. In years of drought the triple spacing has produced the higher yields. The difference is not great, however, and if conditions are severe enough to produce a low yield of milo in double-spaced rows, yields in triple-spaced rows likewise will be low.

Results with wheat following wide-spaced sorghums are meager. Those at hand show that wheat following double-spaced sorghums produces a yield less than 50 percent higher than following sorghums in regular-width rows. Indications are that wheat on double-spaced sorghum land will not produce as high yields as wheat following wheat on early prepared land. At Hays the yield of wheat planted between rows of double-spaced kafir was below that of wheat on early prepared wheatland. At Garden City yields of wheat on double-spaced milo land have been a little higher than on early prepared wheatland, but the rotation containing wheat on double-spaced milo land is in a better location than most of the wheat on early prepared wheatland.

The evidence at hand indicates that the utmost that can be expected for wheat planted between double-spaced sorghum rows is that it will approach the yield of wheat after wheat on early preparation, with the prospect that it may fall considerably short in some years. In dry years double-spaced sorghums are capable of removing practically all available moisture from between the rows.

There is no doubt that as the distance between rows is increased above the distance to which sorghum roots spread, the yield of wheat is increased. The space between the rows becomes to all intents and purposes a summer fallow. Whether wheat on wide-spaced sorghum land will ever equal the yield of wheat on fallowed land appears doubtful.

Growing sorghum in very wide spacings (16 feet or more between rows) and planting wheat between the rows has been widely advocated as a means of preventing wind erosion of wheatland. Very little of it has actually been done. These wide spacings need to be tested on a larger scale than is possible with the limited acreage and small-sized plots on field stations. There would appear to be no reason why the soil between the wide-spaced rows should not be at least as ready to blow as on fallowed or early prepared land. The only question is whether rows of sorghum at intervals through a field can check wind velocities enough to reduce soil movement materially.

A practical advantage of growing wide-spaced sorghums is the fact that it necessitates early cultivation. It is necessary to cultivate the land reasonably early to prepare for the sorghum, and this cultivation destroys weeds. All too frequently, cultivation on land to be fallowed is delayed until weeds have removed most of the moisture from spring rains. Where cultural operations are started in time and weeds are kept under control, fallowed land can be depended on to contain more moisture at seeding time than land where a wide-spaced sorghum has been grown, because the growing crop uses the moisture for several feet each side of the row. If the growing of wide-spaced sorghums, however, is an inducement to give early cultivation to land where preparation would otherwise be delayed, it serves a useful purpose.

In many years, particularly when wheat fails, whether or not sorghums in wide-spaced rows will produce as many bushels per acre as in ordinary width rows is a matter of little importance. In such years, the question is whether the wide-spaced sorghum will produce a yield of grain or of forage tall enough to harvest when sorghum in conventional width rows may be too short. It is further likely that in such years it will be necessary to plant more than the usual acreage of sorghum in order to try to insure a feed crop, and that many acres will be planted to sorghum that are ordinarily reserved for wheat. In such cases, wide spacing of the sorghum both for the purpose of insuring a feed supply and as a preparation for wheat is highly desirable.

PASTURES AND PASTURE CROPS

It is not the intention to go into detail regarding the different pasture crops, but since the production of livestock necessitates the use of pastures, some mention of them is desirable. The less certain crop production is in a given area, the greater must be the dependence placed on pasture. There are three principal types of pastures—native grass pasture, small grains used for pasture, and summer pasture crops. The chief function of the summer pasture crops is to furnish green pasture at a time when native grass is at a standstill.

NATIVE GRASS PASTURES

In some of the area, the land now in native pasture is largely the rough and hilly land not adapted to cultivation. Such land will undoubtedly remain in native grass. In much of the area there are still large acreages of land which have not been broken up, the topography of which is suitable for farming. Much of this grassland has been badly injured during the past years by drought, overgrazing, and by soil blowing from adjacent fields and has thus become relatively unproductive. However, Savage (*12*) has found that in nearly all cases there is still enough native grass to form a cover rapidly under normal or above-normal rainfall conditions, if the land is given reasonable protection. Such rainfall is necessary if crops are to be produced, and a rainfall sufficient to produce a crop on such land if broken out will enable the land to go a long way toward resodding itself.

If the risk element in crop production is at all high, grave consideration should be given to the question of whether the land is not worth more for grazing in connection with crop production than for crop production alone before destroying the sod. Once broken, land not producing profitable crops becomes a liability rather than an asset.

It is popular to state the hackneyed truth that much land has been broken that should not have been broken, and to state further that any land still in grass should remain untouched. Whether or not this is done will depend upon economic conditions. The real inducement to leave land in grass, or to reseed to grass land that is already under cultivation, will come when land in native grass shows a profit. In the hard lands of the area the most abundant native grasses are grama and buffalo. While these are valuable for grazing, their carrying capacity is not high, and a relatively large acreage is required for each animal grazed. If the taxes and other fixed charges on the

land are so high that the returns from the animals grazing it are not high enough to more than cover expenses, there is little inducement to keep land in grass. A lesser tax rate on land that is in pasture would do much to maintain or increase the acreage of native grass.

Native grass pastures are valuable for grazing in connection with crop production. They furnish a place to graze livestock at any time when they cannot be kept on cropland. Many farmers have broken so much of their land that the remaining pasture land is badly abused. The necessity of keeping stock on these small pastures much of the year has resulted in overgrazing to an extent injurious to the grass and unprofitable in the returns from the livestock. The grass is grazed at any or all seasons, and the more serious conditions become, the greater is the necessity of keeping the livestock on the grass pasture. Many farmers would gladly increase their grass acreage, but no tame grass has yet been found that appears to be well adapted to the section. Regrassing by natural means requires a lifetime, and during the resodding process the land is of secondary value as pasture. Replanting to native grasses such as grama, while promising, is still in the experimental stage. The difficulty of reseeding land once broken is an additional reason for serious consideration before breaking sod.

Where adequate native pasture is still available, it is possible that the pasture can be kept in better condition and furnish more grazing by adopting better management practices. In other sections practices such as deferred and rotation grazing have greatly increased the carrying capacity of pastures, and have at the same time protected the grasses from overgrazing and consequent destruction. Investigations in pasture management that would help determine the best method of utilizing native pastures should contribute much to making them more valuable. A study of methods of controlling pasture weeds is likewise important.

Practices such as contour listing of pastures to keep all the rainfall on the land have in some instances shown much promise of increasing their productivity. Further systematic research along these lines to determine what practices are best under the many combinations of conditions on the Plains should be carried out most earnestly. The greatest urge to reestablish native grass pastures will come when present native pastures are made more valuable.

During the past few years lands still in native grass have had a value far beyond that of the feed they have furnished. They have stood the brunt of soil blowing from adjacent lands and have acted as buffers against the increase of areas of destructive soil blowing. The protection they have afforded in this way is beyond measure.

SMALL GRAIN FOR PASTURES

Winter wheat is used as a pasture throughout the area. Swanson (*13*) and others have shown that a heavy fall growth of wheat may be grazed without reducing the prospective yield. In most cases the yield has been increased. On the other hand, pasturing a light growth of wheat has usually reduced grain yields. In much of the area under consideration there are many years when the fall growth of wheat is poor. Grazing under such conditions not only reduces the prospective yield, but the removal of the top growth and the trampling of the stock increases the danger of damage from soil blowing. In most

cases it would be more profitable to plant a field early for the purpose of furnishing fall and winter pasture than to pasture the whole wheat acreage. When the whole wheat acreage is pastured the tendency is to plant wheat somewhat earlier than is desirable for maximum grain production, in order to provide pasture. A heavy fall growth of wheat that may be benefited by pasturing is most likely to occur on fallowed land, and there are farmers who make a practice of growing wheat on fallowed land to provide a fall growth sufficient for pasture. Other winter grains in the area may provide pasture equal to that provided by winter wheat. None of them, however, is as productive of both forage and grain, and it is not probable that they will compete with winter wheat as pasture crops.

SUMMER PASTURES

The two principal summer pasture crops are Sudan grass and sweetclover. Of these two crops, Sudan grass is by far the more dependable. Pasture records are not available on the dry-land stations, but hay yields show that at Dalhart Sudan grass was never a total failure during the period 1914–32. No crop was obtained during the exceedingly dry year 1933 and only a very light yield in 1934. Records at the Kansas State branch station at Tribune show that during the period 1922–34 Sudan grass was never a complete failure, but in the years 1926 and 1934 the quantity of pasture furnished was small. On an average 1 acre of Sudan grass furnished a little more than 70 days of pasture for one mature cow.

The greatest value of Sudan grass is that it furnishes green pasture at a time when native grass pastures are making no growth. Its chief disadvantage is that it is an annual crop that must be planted each year. Occasional livestock losses from cyanide poisoning occur.

Sweetclover has been successfully used as pasture in many years. Its chief value is that it is a legume. Its drawbacks are that there is some difficulty in getting a stand and that the sweetclover plants may die during a hot, dry summer. At least on some soils sweetclover mellows the ground to such an extent that it increases the hazard of soil blowing. Land that has been in sweetclover should not be summer- or fall-plowed and allowed to go through the winter without a protective cover.

FARMING SYSTEMS COMPARED

The following discussion is for the purpose of giving a picture, constructed from rainfall records for Richfield, Kans., of crop production as it might have been during the entire period that rainfall records are available. There is no pretense that these estimated yields are accurate, or that they closely approach the yields actually obtained in each individual year. It is probable, however, that the number of years of failure, fair crops, and good crops are closely approximated. The estimated yields are given in table 19.

Since the yields in the table are computed from precipitation records, failures due to such causes as hail, rodent damage, plant diseases, and winter-killing are not included.

The assumption is made in the instance shown that the soil is of the hard-land type but is not too heavy to prevent penetration of water and roots, and that the soil is deep enough to store at least 7 inches of available water.

The estimates given are the total yields that might have been obtained on 600 acres of cultivated land during the period covered by the precipitation records. In one case the entire acreage was planted each year to wheat on early prepared land. It is hardly probable that the entire acreage would have been prepared early, but the figure is presented as the maximum production obtained on land continuously cropped to wheat. In the second case the 600 acres were cropped on an alternate fallow and crop basis; that is, 300 acres were in fallow each year and 300 acres in wheat.

TABLE 19.—*Calculated total yields of crops obtained from 600 acres of average hard land in southwestern Kansas, under three different methods of cropping*

[Precipitation at Richfield used as a basis for calculation]

Crop year	First method (600 acres wheat after wheat on early prepared land)	Second method (300 acres wheat on fallow, 300 acres fallow)	Third method (500 acres planted as shown; 100 acres fallow after row crop)			
			100 acres wheat on fallow	300 acres wheat after wheat on early preparation	50 acres milo after wheat	50 acres kafir after wheat (total weight)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Tons*
1892	10,200	6,900	2,300	5,100	850	97.5
1893	0	0	0	0	300	32.5
1894	5,400	2,700	900	2,700	1,100	122.5
1895	6,000	4,800	1,600	3,000	1,400	157.5
1896	3,600	3,300	1,100	1,800	0	.0
1897	0	0	0	0	700	75.0
1898	6,000	4,500	1,500	3,000	950	107.5
1899	0	2,700	900	0	750	80.0
1900	12,600	6,900	2,300	6,300	1,050	120.0
1901	0	4,500	1,500	0	700	80.0
1902	6,000	4,200	1,400	3,000	650	72.5
1903	6,600	5,100	1,700	3,300	750	80.0
1904	0	2,400	800	0	750	82.5
1905	9,000	5,400	1,800	4,500	900	102.5
1912	13,200	7,200	2,400	6,600	950	110.0
1913	0	2,100	700	0	0	22.5
1914	7,200	3,600	1,200	3,600	750	80.0
1915	15,600	9,900	3,300	7,800	2,150	242.5
1916	0	4,800	1,600	0	450	47.5
1917	0	0	0	0	550	60.0
1918	0	0	0	0	600	67.5
1919	13,800	7,500	2,500	6,900	1,350	147.5
1920	0	5,100	1,700	0	1,200	132.5
1921	9,600	6,300	2,100	4,800	1,050	117.5
1922	6,000	5,400	1,800	3,000	800	87.5
1923	0	0	0	0	600	65.0
1924	7,200	5,100	1,700	3,600	700	77.5
1925	0	0	0	0	600	67.5
1926	4,800	3,000	1,000	2,400	500	57.5
1927	0	0	0	0	850	92.5
1928	10,800	6,300	2,100	5,400	1,150	127.5
1929	9,600	7,500	2,500	4,800	1,200	132.5
1930	0	3,600	1,200	0	450	50.0
1931	12,000	6,600	2,200	6,000	1,300	142.5
1932	4,800	6,000	2,000	2,400	400	45.0
1933	0	0	0	0	350	37.5
1934	0	0	0	0	0	15.0
1935	0	0	0	0	0	.0

In the third case, it was considered that 300 acres were planted to wheat after wheat on early preparation, 100 acres planted to kafir and milo, the 100 acres of kafir and milo stubble were left fallow, and 100 acres were planted to wheat on fallow. A computed yield of 5 bushels or less of milo is considered zero, as the heads would have doubtless been too small to harvest. When the yield was less than 10 bushels per acre, or the total production of the 50 acres less than 500 bushels, it is very probable that only the larger heads would have been harvested.

The estimates of crop production under the different systems is presented for the sole purpose of giving a visual picture of the crops that might have been expected under the different cropping systems. Comparison of bushels per acre between fallowed and cropped land is often misconstrued, because the fact is often overlooked that where fallow is used only half of the land is in wheat.

Table 19 is given with the full realization that in some years, as in 1914 and 1926, the calculated yield is too low, whereas in others it may be too high. The figures, however, give what is believed to be a reliable comparison of the surety of crop production under the different farming systems employed.

The example given is from the precipitation records for Richfield. This station is located near the center of the area, and has a record commencing in 1892 and continuing until 1935, except for the period 1906–11, when no rainfall records were taken. The yields given do not represent what has actually taken place at Richfield, but they represent the normal expectation of crops on the type of soil described under a precipitation equivalent to that at Richfield.

The average acre yield estimated for wheat after wheat on early prepared land for the period was 7.9 bushels and that for wheat on fallow was 12.6 bushels. For reasons given in the discussion of summer fallow, the computed yield may be a little too low.

The total production of 600 acres cropped continuously to wheat would have been higher than the same number of acres in alternate fallow and wheat. The difference would amount to about 1½ bushels per acre per year over the entire period. On the other hand, continuously cropped land must all be prepared, seeded, and harvested each year, which requires more labor, more seed, and a greater seasonal concentration of labor than is required when a portion of the land is fallowed.

The most striking difference between the two systems is in the distribution of yields. With the land all planted to wheat each year, there were 17 of the 38 years when wheat would have failed or would have produced a yield too low to pay for harvesting. The use of fallow would have avoided seven of these failures. The years when fallow would not have prevented failure were for the most part years when the precipitation for the 12 months before seeding was too low to permit much storage of water in fallow. In two of the years, 1893 and 1933, the precipitation during the life of the crop was so low that failure or near failure would have resulted had the soil been filled to capacity at seeding time. In the remainder of the years, except for 1923, the failures on fallow were due principally to low storage of water. In none of these years was the estimated quantity of water stored in fallowed land as much as 3 inches. In 1923 the water stored in fallowed soil was sufficient to have produced a fair crop, but the fall was so dry that it is almost certain that wheat could not have emerged. The same impossibility of obtaining a stand would have caused the 1893 crop to fail regardless of conditions during the spring and summer.

In the 28 years when it was estimated a crop was produced by one or both methods, there were 20 years when a greater total production would have been obtained on continuously cropped wheatland, and 8 years when a greater production would have been secured on the land half of which was in fallow. Nearly all the years when continuously cropped land greatly exceeded fallowed land in yield were

years of high production. The remainder were years following years of drought when fallow had no opportunity to store water. The years when the system of using fallow produced the higher yields were nearly all years when wheat on continuously cropped land was a failure, or produced only a low yield. The better distribution of yield between years brought about by the use of fallow requires no comment.

One feature that requires comment is the distribution of the years when fallowed land would have produced crops while other land did not. During the period 1892–1905 there were only 2 years when wheat on fallowed land showed failure. Records extending over this period of years only, would have indicated that fallow almost entirely eliminated failures. During the period 1923–34 there was only a single year when wheat on fallow produced a crop while wheat after wheat did not. Records extending over this period of years only would have indicated that while fallow increased total yields in some years, it was not at all effective in preventing failures. The records for even a 10- or 15-year period may not be an accurate measure of what may be expected over a long period of years.

In the third system shown, a portion of the wheat acreage is replaced by sorghums. The greater surety of sorghum production is evidenced by the scarcity of estimated failures. There have doubtless been a few failures brought about by causes other than lack of water, but the yields indicate that yields of sorghum, at least feed, are more certain than yields of wheat, even on fallowed land.

Well-cared-for sorghum would, in most cases, provide some feed for a farm herd during dry years when no yield of wheat was obtained. But the low yields of sorghum almost invariably occurred in years when wheat failed. The greater the necessity of producing a feed crop, the greater the probability that only a low yield will be obtained, or that the crop will fail. The failures and the near failures will almost invariably occur when wheat has failed, and the plight of a livestock farmer without feed is not enviable. Only the growing of feed crops in all years and the carrying over of feed from years of good production to years of poor production will insure ample feed for livestock. Even this will not suffice when or if successive failures occur, but successive failures to produce at least a feed crop of sorghums are not likely to occur more than once in a lifetime.

The estimate of yields under the different systems of farming are presented for the sole purpose of showing visually the frequency of failure with continuous wheat, the extent to which failure can be avoided by the use of fallow, and the comparative surety of sorghums. The third system presented is not presented as an ideal farming system, but illustrates the extent to which complete failure can be avoided by the use of different crops and tillage practices. The growth of forage sorghums and to some extent the growth of grain sorghums necessitates the presence of at least a farm herd of livestock on the farm. With the frequency of failure with wheat in mind, it is reasonable to suppose that a farm herd capable of supplying the family with the necessities of life during the years of wheat failures would be a vital necessity for a farm not having means to carry through such years.

The question might properly be asked as to whether a definite farming system should be followed and designated acreages of land planted

to certain crops each year. In principle it is probably well for a farmer to have at least a general idea of the acreage that he wishes to have in the different crops each year. But the uncertainty of the rainfall makes it desirable that there be a certain amount of flexibility in the cropping practice. The desirability of keeping down the wheat acreage in years when conditions at seeding time are very poor is recognized. The land not planted to wheat may be carried over the next season as fallow or be planted to row crops. If moisture conditions have not improved materially by the time for planting, it will often be desirable to plant all or most of the sorghum in double-width or wider spaced rows. The wide spacing makes a greater possibility of producing a yield of sorghum that can be harvested, and at the same time provides a fair preparation for wheat, if conditions are at all favorable the next fall. A farmer can then plant his customary acreage to wheat without the severe reduction in yield that usually results when wheat follows sorghum that has been planted in conventional width rows. If conditions are still unfavorable at the time sorghums are planted, at least a part of the acreage should be held back for the purpose of planting quick-maturing varieties should favorable weather occur at a later date.

The uncertainty of the rainfall within the area makes planting a definite acreage of the different crops each year almost an impossibility. The acreage devoted to the different crops must be suited to the farm needs and to the probabilities of success as evidenced by conditions at seeding.

With any system of farming that includes livestock production, the greatest emphasis must be placed on the production of forage. A dependable supply of forage can better be obtained by planting some sorghums in years that appear favorable for wheat, than by planting sorghums chiefly in years when conditions at wheat seeding time have been poor, or when wheat has failed. The carrying over of feed from good years, either in the stack or as silage, would appear to be one of the best means of making farming safe.

DISCUSSION

The studies reported in this circular were undertaken for the purpose of determining the relative number of failures, poor to fair crops, and good crops that might be expected under different average quantities of precipitation in a portion of the southern Great Plains.

Everyone recognizes that with a given type of soil and within the range of precipitation with which this study deals the frequency of failures with wheat is increased as the precipitation is decreased. Very few persons, however, realize the drastic reduction in good crops and the increase in failures that may be brought about by a decrease of a single inch in average precipitation. Knowledge of what may be expected over a long period of years should assist in determining whether the prospects of success under particular conditions are such that operations can continue without change, or whether cropping practices must be adapted to expected production.

The number of failures with wheat, in comparison with the number of good crops, should form a basis for determining what crops to grow, what cropping practices to use, and whether and to what extent livestock production must enter the farm program. A farm in an area where wheat after wheat fails 4 years in 10, if farmed exclusively to

wheat, must be capitalized to endure that many years of failure and organized to profit enough from the number of good crops to make up for these failures, if it is to continue under that type of farming. The extent to which failures may be avoided and yields equalized between years through the use of fallow on soils responding to fallow forms a basis for determining to what extent this practice may be a stabilizing influence.

Particularly in the lower rainfall groups, a comparison of the number of good years with the number of failures to be expected should be a positive aid in determining the sections where wheat production is too hazardous to offer even a fair chance of success.

The yields of sorghums which may be obtained in the different rainfall groups indicate what dependence can be placed on the sorghums. Comparison of sorghum production with wheat production in similar rainfall groups gives a measure of the extent to which sorghums may be relied on to avoid total failures in years when wheat fails. The arrangement of sorghum yields into classes according to the rainfall groups shows the sections where sorghums must be depended upon for forage rather than for grain, except as grain yields are modified through the use of wide spacings or fallow.

Within all of the rainfall groups, the number of failures with wheat may appear high. But comparison of actual and estimated yields under known conditions shows that in practically every case the number of both failures and poor crops actually obtained is as high or higher than the estimated number.

In actual practice the number or extent of failures, even under continuous wheat production, can be modified to some extent by management practices. In plot experiments from which these studies were made crops are planted regardless of moisture conditions and are allowed to grow to maturity regardless of whether or not a profitable yield will be produced. In farming practice, planting under poor conditions can be restricted. Crops injured beyond recovery early in the season may be abandoned and the land kept fallow during the summer. This gives a better chance of growing a crop the next year than there would have been had the crop been allowed to mature.

Wheat farming by continuous methods is subject to failures throughout the area, the risk increasing with decreasing average precipitation. Any farming based on this method of growing wheat, even in the most favorable localities, must be well capitalized, or reserves must be carried over from years of good production if the years of failure are to be endured without outside assistance.

Summer fallowing has been effective in stabilizing the yields of wheat to some extent throughout the area on soil types that respond to fallow and under a rainfall sufficient to enable fallowed land to store moisture. A wheat grower systematically using fallow has less years of failure to contend with than one growing wheat continuously, though he will produce less wheat in productive years. It is probable that on the average the net returns may be as great, as the cost of production is slightly lower and the smaller total quantity of wheat produced may bring a higher price, because more wheat will be grown in years when there is less total production.

Too much stress cannot be placed on the necessity of doing a good job of fallowing, if it is to be done at all. Improperly cared-for fallow fails to conserve moisture and creates a soil-blowing hazard. The

use of fallow on soils not capable of absorbing and retaining material quantities of water must likewise be guarded against.

In all of the area sorghums were less subject to failure than wheat, though the sorghum yields declined with decreasing rainfall in the same manner as did those of wheat. Sorghum production, particularly of grain, was materially increased through fallowing, but with fallowing there was an additional danger of wind erosion during the winter, unless steps were taken to prevent it. The percentage increase in favor of fallowing was nearly as great for sorghums as for wheat. There is, however, less need for growing much sorghum on fallowed land in the better wheat areas. Sorghum planted after wheat usually yields well. Sorghums in wide-spaced rows, while not so productive as on fallowed land, are not likely to fail except in the exceedingly adverse years. This wide spacing fits in admirably with wheat production. Most of the fallowed acreage might better be planted to wheat than to sorghums. In sections where wheat production is risky and even sorghum production none too certain, it is possible that fallowing for sorghums would be a valuable means of insuring a feed supply.

In the study of sorghums, the results have been based on yields obtained on land that was disked or plowed before the weeds had made much growth in the spring, and where clean cultivation was practiced while the sorghum crop was growing. Allowing weeds to consume moisture in the spring, or allowing them to grow in competition with the sorghums, would have reduced the yields and materially increased the number of failures. Timely planting is also important; many farmers plant too early to obtain the best yields.

The question of soil blowing or wind erosion has been dealt with only incidentally in this study, although it is at present the greatest problem with which the area is confronted. Bringing this under control is the important problem at present, but after this has been done the question will arise as to what are the future prospects of the area. This study provides material on which a partial answer may be based.

If droughts of the intensity of the present one were to prevail indefinitely, taking most of the area permanently out of production would be the only solution of the whole problem. But past precipitation records show that while droughts occur at intervals over the area, those of the length and intensity of the present one occur rarely. The return to normal or above-normal conditions may occur at any time.

This study endeavors to point out what normal conditions are. The period of greatest development was one of above-normal precipitation and below-normal failures. What must be done is to take the probable number of failures with wheat into consideration and to establish a farming system that will permit the operator to carry on during the years of failure to be experienced. Greater attention to the production of forage crops as a means of insuring a feed supply for a farm herd and to pastures for maintaining such a herd appears to be an essential means of doing this.

It is easy to recommend the carrying over of feed for drought periods, but the carrying over of enough feed to avoid distress under droughts of several years duration is out of the question. Exhaustion of feed supplies and reduction in farm herds in such years is inevitable.

Past experience leads the writers to believe that such droughts as the present may not recur in a lifetime. The estimated yields of forage and grain sorghums were lower during the 4 years 1932–35 than for any similar period since precipitation records were started.

It is definitely too risky to use for crop production large tracts of land that proved to be unproductive when broken, and shallow soils that have been injured by wind erosion. Other sections are too sandy to be controlled under cultivation. The regrassing or reestablishing of a vegetative cover of some nature on such lands where it has been destroyed is important. At present they are a menace to surrounding land. When put to proper use they should be an asset. There is also land broken for wheat where precipitation is so low that paying yields can be expected only in very favorable years. Such land should also be retired from cultivation.

Within the area, soil and precipitation are the two chief controlling factors in crop production. One soil may be more productive than another in the same locality. But it will not be more productive than a similar soil under a higher rainfall. Throughout the area the quantity of crops produced is limited practically every year by the precipitation.

The conclusions reached in these studies should not be applied outside of the area from which they have been drawn. Water use by crops is influenced greatly by the severity of climatic conditions. Results applicable to this area are not applicable to those of higher humidity, or to those where temperatures are modified by altitude or latitude. Within the limited area to which they apply, it is believed that they furnish a reasonably good basis for planning future practices.

SUMMARY

A study was made of the yields of winter wheat and sorghums that might have been obtained through the entire period of years for which precipitation records are available, over a portion of the southern Great Plains.

This area was selected because soil blowing or wind erosion has been prevalent, and because a measure of the crop production could be obtained by studying only two major crops.

Crop production the past few years has been below normal, but during the development period it probably was above normal. The great need at present is to determine normal conditions, in order that producers may adjust their farming operations to the conditions to be met, and so that agencies operating within the area may have information on which to base recommendations. The present study makes use of long-time precipitation records to try to determine what constitutes normal conditions.

The area is one of high summer temperature and frequent droughts. Both precipitation and humidity decrease from east to west. The elevation increases in the same direction, which modifies temperatures slightly and compensates at least partially for the lower humidity.

Wind erosion is at present the greatest problem over the entire area, but on the better agricultural lands it is controllable, and with the return of normal rainfall and a consequent better vegetative cover, soil movement can be checked by methods long in practice at experiment stations, and by other practices now being used by the Soil Conservation Service, although not in general practice by farmers. Soil drifting has in the past caused much damage, but it has taken the

present widespread devastation to concentrate serious study upon it. From the present study it seems certain that drifting of soils will always be a menace. Increasingly better control methods will no doubt be developed, but on lands where crop failures occur frequently wind erosion will remain a constant threat.

Data from experiment stations show that the use of water is closely related to wheat yields. By means of an arbitrary formula, which eliminated the portion of the summer's precipitation not retained by the soil, it was possible to estimate wheat yields over the area with a reasonable degree of accuracy. The yields estimated from the precipitation of individual weather stations were then assembled by average precipitation groups and the relative number of good crops, poor to fair crops, and failures was determined. These figures give a good basis for determining probable wheat production under the precipitation of any part of the area, provided recommended cultural practices are used. It was found that a difference of a single inch in average precipitation made a material difference in wheat production. A decrease of an inch in annual precipitation meant a smaller number of good crops, a higher number of failures, and, what is still more important, a material increase in the number of times consecutive years of failure might be expected. Comparison of the number of good crops and the number of failures to be expected with wheat should form a good basis for determining the importance that should be given the crop in any part of the area.

Precipitation alone was a good basis for estimating sorghum yields. Sorghums are harvested in the fall, and the loss of water by evaporation during the period between harvest and seeding is a much smaller factor than with wheat. Complete failures were much less frequent than with wheat, but with decreasing average precipitation there was an increasing number of years when sorghum would have produced only forage. Yields were higher and failures much less frequent on sandy loam soils than on soils with a finer texture.

Where failures with wheat are as frequent as they are, even on the better parts of the area, it is apparent that a farmer must have some resource other than wheat if years of failure are to be endured. Livestock and poultry, that will furnish a living for the family in years when wheat fails, appears to be a means of accomplishing this end. Production of livestock means production of sorghums and maintenance of pastures sufficient for the needs of the livestock.

Summer fallowing offers a means of stabilizing wheat yields over most of the area on soils responsive to fallowing, but the use of fallow will not entirely prevent failures. On very heavy, very sandy, and shallow soils there is little response to fallow.

On soils responsive to fallowing, sorghum and wheat production may be combined by fallowing for wheat land on which sorghum has been grown. On soils not so responsive to fallowing or in years when a large acreage must be planted to sorghums, wide spacing of sorghum rows is a valuable means of getting sorghum land back into wheat without the severe reduction in yield that occurs when wheat is planted after sorghum in conventional width rows.

The infrequent failures with sorghums and particularly failures to produce grain almost invariably occur in years when wheat has failed. This is because droughts that cause wheat to fail prevent the storage

of moisture for sorghums. This points to the desirability of growing some sorghums in all years and of carrying over reserves of feed.

The period of most rapid development in the area was one of above-normal rainfall and crop production. Permanent agriculture must be based on the expectation of lower average yields and more failures than were experienced during the period 1920–31.

The present period of drought has been so severe in every part of the area that no cropping system would have provided adequate feed for the maintenance of a farm herd. Under such conditions distress is inevitable. Past climatic records are too short to indicate how frequently such droughts may occur. The available records indicate that the only other drought on record in the section that might have been at all comparable with the present one in length and intensity occurred in 1893 and succeeding years. The meager precipitation records indicate that as a whole sorghum production should have been better then than during the present drought.

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